JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 2008, **90,** 235–248 NUMBER 2 (SEPTEMBER)

AN INVITATION TO BEHAVIOR ANALYSTS: REVIEW OF IN SEARCH OF MEMORY: THE EMERGENCE OF A NEW SCIENCE OF MIND *BY ERIC R. KANDEL*

FRANCIS MECHNER

This fascinating autobiography and multifaceted case history in neuroscience research is accessible to laymen and potentially instructive to working scientists. Kandel takes the reader through his thought processes as he describes experiments that led to some of the past decades' major neuroscience discoveries (some highlights of which are summarized in the review's Appendix), and eventually to his Nobel Prize. The review analyzes some of the terminological and conceptual issues that have often inhibited communication between behavior analysts and neuroscientists, with special attention to some of Bennett and Hacker's admonitions viewed from the perspective of language evolution and linguistics. The review then discusses opportunities for behavior analysts to collaborate with neuroscientists by applying behavioral contingency analysis to help specify the independent variables of neuroscience experiments described by Kandel. Finally, it examines Kandel's provocative heuristics for locating important research problems, and the lessons that can be gleaned from the book regarding the attributes of potentially great achievers.

Key words: cognitive neuroscience, contingencies, scientific behavior, scientific method, terminology, the mereological fallacy, reductionism

---

The physiologist of the future will tell us all that can be known about what is happening inside the behaving organism. His account will be an advance over a behavioral analysis, because the latter is … confined to functional relations showing temporal gaps. Something is done today which affects the behavior of an organism tomorrow. No matter how clearly that fact can be established, a step is missing, and we must wait for the physiologist to supply it. He will be able to show how an organism is changed when exposed to contingencies of reinforcement and why the changed organism then behaves in a different way, possibly at a much later date. — B. F. Skinner, 1974, pp. 236–237

The deficiencies in our description would probably vanish if we were already in a position to replace the psychological terms by physiological and chemical ones … —Sigmund Freud, 1922

If Freud and Skinner were alive today, they might well agree that Kandel's work is what they had in mind when they wrote those comments. Both began their scientific careers in the physiology laboratory, to which neither of them ever returned. Kandel made the reverse journey: from being a Freudian psychoanalyst disillusioned by that field's unscientific direction, he proceeded on a path that took him into the physiology laboratory and in 2000 to Stockholm where he accepted the Nobel Prize in Physiology or Medicine for decoding the biochemical and molecular mechanisms of learning and memory.[1]

Kandel's detailed account of the stream of discoveries that have progressively been fulfilling some of Skinner's and Freud's anticipations is not just that of a great scientist whose own work it describes, but also that of a master science writer, story teller, philosopher of science, and humanist. He laces the story with intimate and sometimes gripping autobiographical details as he discusses the personalities, motivations, thought processes, hypotheses, fumblings, sources of inspiration and personal lives of dozens of the field's leading contributors.

This approach is valuable in three ways. First, it can inform us of some important recent advances in neuroscience, highlights of which are summarized in the Appendix following this review. Second, like all great case histories, it contributes to answering such perennial questions as: What do good scientists do? What are the conditions that produce them? What predictive characteristics identify them? Skinner (1956), Marr (2003a), and others have made the point that case histories

[1] Kandel has also been awarded the National Medal of Science, the Wolf Prize, the Gairdner International Award, the Charles A. Dana Award and the Lasker Award. *In Search of Memory* was awarded the 2006 Los Angeles Times Book Award for Science and Technology. Kandel is also co-author of the widely used textbook ''Principles of Neural Science.''

doi: 10.1901/jeab.2008.90-235

tend to be of more help in answering such questions than philosophers of science. I will return later to ways in which *In Search of Memory* bears on such questions.

And third, Kandel suggests an interesting heuristic for identifying potentially fruitful directions and strategies for scientific research. Some behavior analysts ponder such questions as: In what directions can behavioral science now progress? How can behavior analysis continue to move forward as an experimental science and not just as a series of applied technologies? What might be some of the field's next great challenges? Kandel makes the provocative suggestion that the best place to look for answers to such questions is at the boundaries of disciplines:

> Few things are more exhilarating than bringing a new way of thinking to another discipline. This cross-fertilization of disciplines is what Jimmy Schwartz, Alden Spencer, and I had in mind … when we called our new division at NYU ''neurobiology *and* behavior.'' (p. 310)[2]

Ernst Mach makes a similar point in *Analysis of Sensations:*

> … they [two different fields of science] may come into closer contact, when it is noticed that unexpected light is thrown on the doctrines of one by the doctrines of another … the temporary relation between them [the fields of science] brings about a transformation of our conceptions…. (Mach, 1914/1959)

This heuristic makes sense when we consider that demarcations and boundaries of scientific disciplines do not exist in nature — they just reflect primitive efforts to categorize a natural universe we have barely begun to understand. Since there is only a single natural universe for scientific disciplines to explore, the expansion of their domains within this universe must inevitably bring them into increasing contact. That is what we are currently witnessing in the case of neuroscience and behavior analysis.

But boundary contact also entails frictions. A review of a neuroscience book for this journal would be remiss if it did not address some of these, given how they often inhibit communication and collaboration between these two fields.

[2] All references to *In Search of Memory* will be indicated by page numbers only.

TERMINOLOGICAL, SEMANTIC, AND CONCEPTUAL ISSUES

The contentions at discipline boundaries tend to occur mostly in the realms of terminology, semantics, and conceptualization. Because those types of issues tend to loom large when behavior analysts read a book like Kandel's, I will devote a significant part of the review to attempts to bring them into perspective.

The language of every discipline evolves continuously, through processes of importing terms, coining new ones and phasing out others. The imported terms are then usually used in novel ways. Let's look at some familiar examples.

Physics imported force, mass, energy, time, space, atom, particle, etc.; it coined voltage, joule, photon, electron, proton, etc., and phased out phlogiston, earth, air, ether, essence, etc. Chemistry imported and phased out many of these same terms, and imported bond, element, heat, charge, acid, base, fat, and the names of most metals. It coined oxidation, benzene, hydroxyl, ketone, halogen, etc. Biology imported life, cell, membrane, plant, evolution, the names of many organs, etc.; it coined paramecium, bacterium, virus, protein, mitochondria, DNA, RNA, etc.; and phased out *vis viva*, spirits, humors, phlegm, etc.

Behavior analysis imported behavior, motor, response, stimulus, learning, conditioning, reinforcement, schedule, extinction, punishment, avoidance, discrimination, generalization, drive, sensation, perception, memory, visual, seeing, hearing, emotion, thinking, attention, choice, etc. and coined operant, respondent, mand, IRT, etc. Neuroscience imported many of these same terms, as well as brain, mind, mental, representation, map, storage, image, visualization, etc., and many terms from biology, and coined neuron, axon, ganglion, synapse, dendrite, cortex, etc. For both current behavior analysis and neuroscience, the phasing out process has not yet proceeded long enough to permit it to be viewed with any real perspective.[3]

[3] I am reluctant to discuss so-called cognitive psychology as a separate discipline because the extremely heterogeneous set of activities so designated range from metaphysical word games at one extreme to important behavior research at the other, and any effort to categorize these activities would not be germane to the point being made here.

THE EVOLUTION OF TERMINOLOGIES AND CONCEPTS

One thing these examples show is that adjacent disciplines often import the same terms but then use them differently, and that over time, terminologies and concepts, like theories, are phased out and replaced by more useful ones. This process accelerates when the measurement technology of one discipline is applied to the phenomena of the other. For example, the invention of the telescope revolutionized astronomy; the microscope, biology; and the spectrometer, chemistry.

Kandel shows us how the technologies of single-cell recording, recombinant DNA, PET and fMRI have similarly produced far-reaching changes in certain conceptualizations in psychology, behavior analysis, and neuroscience. We may also be seeing this process at work in ongoing discussions of whether neural or other internal processes should qualify as behavior (Marr, 2003b, pp. 76–77; Moore, 2008, Ch. 4), and there are different views as to the necessity of overt muscle engagement, i.e., movement (Hefferline & Keenan, 1963; Jacobson, 1932), or even of covert engagement (Mechner, 1992, pp. 12–18). Thompson (2007) makes the related points that the behavior repertoire has the status of a biological system, like the digestive or circulatory system, that behavior itself has the status of a biological function, and that distinctions between endogenous and external events are biologically and epistemologically problematical.

In Search of Memory should be read with the perspective that we are living in an epoch in which the terminologies and concepts of the related life science disciplines, and their very boundaries, are undergoing rapid change.

A HISTORICAL PERSPECTIVE

How did the terminological and conceptual issues between neuroscience and behavior analysis come about? The power and appeal of Skinner's approach is based in part on the idea that the same rigorous experimental, empirical, and quantitative methods that had proven spectacularly successful in other areas of natural science can also be used to study the behavior of organisms (Skinner, 1938, 1953). But the behavior so studied had to be objectively observable with the instruments that contemporary technology provided. This requirement appeared to exclude the study of entities that Skinner termed ''private events'' — thinking, emotion, and other ''mental processes,'' — which constituted much of the domain of traditional psychology.[4]

Not surprisingly, the resulting no-man's land was promptly preempted by psychologists who were less committed to the rigors of empirical science. They freely imported the terminology of colloquial parlance without concern for observability, and did not hesitate to postulate hypothetical neural mechanisms as presumptive explanatory constructs.

Kandel, though he applied some of Pavlov's paradigms in his research, often comments on why neuroscientists, in their explorations of neural correlates of behavioral phenomena, generally found cognitive concepts more attractive than those of the ''behaviorists'' (Palmer, 2003). This preference was reinforced by the discovery of neural correlates of various perceptual processes, visualization, various types of memory, emotion, certain language functions, and of many other behavioral phenomena that cognitive psychologists had been claiming as their domain. Schaal (2003) provides an analysis of these dynamics.

MIND, THE BEHAVIOR REPERTOIRE, AND MEMORY

The multiplicity of usages that the term ''mind''—arguably one of the life sciences' most popular imports—has received makes it an active arena for controversy. Kandel (and many other neuroscientists) use the term mind in a way that is consistent with the Aristotelian conception (not an entity but a set of powers, capacities, and potentialities), and to Bennett and Hacker's (2003, pp. 62–63) ''a distinctive range of capacities.'' When used in this way, the term mind can generally be replaced by ''behavior repertoire''—the potentiality for the occurrence of any of the individual's operant behavior. This may well

[4] Travis Thompson (2007) and others have pointed out that endogenous biological events (e.g., circulatory, endocrine, digestive), whether or not they are consciously perceived, are ''private'' in the same sense as behavioral and neural endogenous biological events, and that these can be accorded the same status as more easily observed ones.

be an important translation key that behavior analysts bring to the communication challenge.

The term ''knowledge'' is generally applied to a certain subset of the potentialities that comprise the behavior repertoire. For example, Bennett and Hacker (2003, p. 164) say that ''…knowledge is an ability.'' Thus Kandel's question, ''How does mind acquire knowledge of the world?'' (p. 9) would then be translatable into ''How does a behavior repertoire come to include the subset 'knowledge of the world?'' and the ''disposition'' concept (Cross, 2005; Ryle, 1949) could be viewed as a conditional probability parameter of the behavior repertoire's components.

In Search of Memory shows us that the concept of memory requires extensive parsing when used in the sense of the potentiality for the reoccurrence, after a time, of the behavioral effects of a learning or perceptual episode. Current categorizations include short-term, long-term, declarative, episodic (Eichenbaum & Fortin, 2005), intrinsic, working (Goldman-Rakic, 1995b), experiential, factual, visual, auditory, and spatial (Kandel, pp. 282–284; O'Keefe & Dostrovsky, 1971). The continued identification and brain mapping of the multiple anatomically distributed sites at which these potentialities of the behavior repertoire are stored, and the ''nestedness'' of those and other sites (Schaal, 2003), are current frontiers of neuroscience.

BENNETT AND HACKER'S CRITICISMS OF USAGES

Bennett and Hacker (2003) expose as misconceived many of the issues that currently preoccupy some neuroscientists and philosophers, but their criticisms become too general when they take aim at certain of Kandel's and other neuroscientists' uses of language. The essence of their criticisms, based on a kind of connectivity analysis, is that terms may be used only in accordance with certain a priori semantic and syntactic rules and in conformity with their usages in ordinary parlance and the dictionary. Violation of those usages, they claim, results in ''incoherence'' and ''profound confusion.'' Bennett and Hacker also propose what they call ''the mereological principle,'' which holds that it is fallacious and incoherent to attribute to parts of an organism psychological predicates that can ''meaningfully'' be attributed only to the organism as a whole (pp. 68–107). ''Says who?'' is a pithy capsule summary of J. M. Sytsma's (2007a, 2007b) critique of this principle. The essence of his critique is that Bennett and Hacker's standard of correct usage runs counter to empirical linguistics (e.g., Gonzalez-Marquez, Mittelberg, Coulson, & Spivey, 2007) and to the view of language and verbal behavior as a subject of study by the methods of empirical science (e.g., Skinner, 1957).[5] Another reviewer (Kohler, 2003) commented that ''Bennett and Hacker render their conclusions immune against empirical results by their exclusively *a priori* style of reasoning.''

MEANINGFULNESS AS AN EMPIRICAL ISSUE

The relevant issue in evaluating the ''meaningfulness'' and acceptability of usages would seem to be the empirical one of their communicative effectiveness among their users. Bennett and Hacker (2003) offer no evidence that any specific usage has ever actually resulted in a misunderstanding or confusion—they just state that it could, would, or should—and often offer, as supposed proofs, invented extreme cases designed to sound ridiculous. In reality, metaphorical or illogical usages within a linguistic community generally do not result in misunderstandings or conceptual confusion: the French double negative—an extreme and notorious instance of illogic—clearly doesn't cause misunderstandings or confusion among native speakers, nor does the English usage of ''quite a few'' and ''quite few'' as opposites. To use Daniel Robinson's expression (Bennett, Dennett, Hacker, & Searle, 2007, p. 186), if there is agreement on usage within a large and highly qualified linguistic community, is it not the outsider who must rethink the matter? The incoherence and confusion is usually only in the eye of the foreign speaker.

I would add that many of Bennett and Hacker's (2003) criticisms also lack the science historian's perspective regarding the inexora-

[5] Bennett and Hacker's (2003) anti-empirical bias is consistent with their dismissive comments about ''behaviorism.''

ble evolution of the languages and conceptualizations of scientific disciplines when their domains expand and their interactions increase. To the assertion that usages must conform to ordinary language, the scientific linguist's first response would be ''*whose* ordinary language, as used in what circumstances?'' The semantic and syntactic evolution of both natural and scientific languages is an ongoing and universal process.

I would certainly not say that all usages and figures of speech are equally useful or can move a science forward; just that it is futile to try to combat the ones we view as inadequate. Whether we consider a particular usage desirable or undesirable, useful or counterproductive, is irrelevant. It's what goes on.

If the sincere goal is to spare cognitive neuroscientists the frustrations of chasing will-o'-the-wisps, the best strategy is to offer them concrete tools with which to do better, and to convince them of their utility. Such tools could include ways to parse or reformulate fuzzy concepts into operationally meaningful ones, and techniques of behavioral contingency analysis for specifying relevant parameters of independent variables.

EXAMINING THE ''MEREOLOGICAL FALLACY'

I am dwelling on the terminology issue at such length partly because Bennett and Hacker's (2003) term ''mereological fallacy,'' which they coined and applied to many common usages including some of Kandel's, has seeped into the vocabulary of behavior analysis (Schaal, 2005) with the effect of adding one more barrier to communication between behavior analysts and neuroscientists, and perhaps even to reading *In Search of Memory*.

I hope to convince the reader that many mereological and related figures of speech often used by Kandel and other neuroscientists are eminently acceptable by virtue of being widely used and understood by their users (Sytsma, 2007a, 2007b). Examples: a nerve ending *detects*, my ears *recognize* a voice, the dog's cochlea *hears* high frequencies, the hemispheres *communicate* via the corpus callosum, the brain *processes*, the brain *interprets* a neural signal that originates in the amputee's stump as pain in the phantom limb, etc. Sytsma defends mereological usages, including some of Kandel's, as common ways of speaking about behavior and neural phenomena. He shows that Bennett and Hacker's ''appropriateness'' criterion of correctness (Bennett & Hacker, 2003, p. 81) fails when applied, for instance, to the perceptual function of an edge-detector neuron:

> To say that the cell sees the edge is simply to say that it responds to visual stimuli in ''appropriate'' ways (it responds by firing or not in a way that corresponds with the presence or absence of a contour). This usage is neither figurative nor confused. It is straightforwardly meaningful, communicative, and useful as a way of describing the behavior of such neurons. (Sytsma, 2007b)

THE STATUS OF METAPHORS AND ANALOGIES

Like many common colloquialisms ('my eyes tell me', 'hold your tongue', 'use your brain', etc.), such figures of speech and metaphors rarely lead to ''profound confusions, misconceptions, and incoherence.'' As Blakemore put it:

> [I do not] think that the employment of common language words (such as map, representation, code, information and even language) is a conceptual blunder … Such metaphorical imagery is a mixture of empirical description, poetic license and inadequate vocabulary. (Blakemore, 1990)

In fact, most imported scientific terms are metaphorical in that they rely on analogy. The new usage is never identical to the original one. The term *energy* was originally used in the sense of an attribute of people, the term *particle* was originally applied only to visible entities, the term *acid* only to the taste of substances, and so forth. The extension of meanings based on analogy and metaphor is part of the process that drives the evolution of scientific languages, perhaps of all languages. Schaal put it elegantly:

> It may be the ability of metaphors and analogies to help researchers accomplish their theoretical goals, and not how well they stand up to connective analysis relative to their conventional counterparts, that is the better basis for approving or disapproving of them (i.e., of figures of speech that involve metaphors or analogies). (Schaal, 2005, p. 691)

Bennett and Hacker counter such arguments by saying that the real problem with Kandel's and other neuroscientists' figures of speech is that they are meant literally rather than metaphorically, as evidenced by the conclusions that are supposedly often drawn from them (Bennett & Hacker, 2003, p. 76), but all of the supposed conclusions they cite are merely extensions of the same metaphors, not new empirical propositions. In scientific parlance, a metaphor is objectionable only when it is used as a pseudoexplanation, thereby obfuscating ignorance and deflecting research attention (Skinner, 1950).

''STORAGE,'' ''RECORDS,'' ''MAPPINGS,'' AND ''REPRESENTATIONS''

Kandel often speaks of memories being ''stored'', in conformity with the general usage that an entity is said to be stored when it continues to be retrievable, like an electric charge (or a potential) in a capacitor, potential energy in a battery or a coiled spring, a document filed in a computer's memory, or biological data in the fossil record. The term *record* is generally used when the stored entity is informational as opposed to a physical object or potential, and is variously termed electronic, magnetic, mechanical, geological, historical, or fossil. When the stored entity is a new behavioral potentiality that resulted from a learning episode (i.e., an addition to the behavior repertoire), the record, we have learned, is a modified neural structure. This is true even if the record is not observed in a particular case, but nonetheless real based on the principle of uniformity (Palmer, 2003, p. 169).

Regarding these usages, Bennett and Hacker make a surprising assertion:

> The idea that in order to remember there must be a neural record stored in the brain is incoherent. For even if there were such a 'record,' it would not be *available* to a person in the sense in which his diary or photograph album is available to him — after all, a person cannot see into his own brain or read Neuralese. (Bennett & Hacker, 2003, p. 164)

But the issue is not the physical record's legibility or availability to the subject. The issue is whether the term *storage mechanism* can intelligibly be applied to the modified neural structures that create the potentialities for the behavior of remembering. Bennett and Hacker's statement that the term *retention* would be acceptable while the term *storage* would not,[6] and that *map* be replaced with the noun *mapping*, seem to me to highlight the pedantry of some of their concerns. On the matter of mappings and representations, Schaal (2005) states, evidently in agreement with Kandel, that neuroscience is moving closer to demonstrating that these are physically observable, and no longer mere hypothetical constructs or cognitive neurologizing.[7]

Taking, again, the science historian's perspective, it seems likely that today's terminological and conceptual controversies will some day be viewed as quaint quibbles, footnotes in the evolution of the life sciences. Just as certain terms that were once widely used are seen with increasing rarity in today's technical literatures— *air* and *weight* in physics; *earth* and *fire* in chemistry; *life* and *animate* in biology—so too may we, over time, see a gradual phasing out from scientific usage of such semantically fuzzy terms as *mind*, *intention*, *awareness*, *consciousness*, *thought*, *memory*, and *emotion*, and their replacement with new and more useful terms and concepts.

POTENTIAL AREAS OF COLLABORATION BETWEEN NEUROSCIENTISTS AND BEHAVIOR ANALYSTS

If I have convinced some behavior analysts to suspend, at least temporarily, possible qualms about some of neuroscience's cognitively-tinged terminology and concepts, I would like to point to some ways in which *In Search of Memory* can be read as an invitation to behavior analysts to collaborate with neuroscientists. Schaal (2003), Green (2006), Timberlake, Schaal, and Steinmetz (2005), Thompson (2007), and Donahoe (2003) have discussed the value of attempts at conceptual synthesis or even collaboration, and I believe that *In Search of Memory* opens the door even wider. For example, it describes many instances of neuroscience research in which behavior

[6] *Retention* is broader than *storage* in that it is applicable also to qualities or attributes, but *storage* is more customary when applied to potentialities.

[7] That is, when the term *representation* is used to describe research results the way Kandel does, not when it is used as an explanation.

analysts can fill an under-appreciated need by offering a powerful tool—their understanding of behavioral contingencies.

Mapping the functions of neural structures often involves correlating recorded neural activity with some behavior. When Kandel (p. 306) cites the study showing that ''…the hippocampus is activated during imagined travel, when a taxi driver is asked to recall how to get to a particular destination,'' he implies that the presumptive independent variable in this study included verbal instructions to the driver in conjunction with certain other experimental conditions, including the driver's history. These, together, comprised the prevailing behavioral contingencies (Dickins, 2005). Mechner (2008a; 2008c) describes a language for analyzing and codifying such contingencies and making their details explicit, precise, and replicable.

APPLICATIONS OF BEHAVIORAL CONTINGENCY ANALYSIS IN NEUROSCIENCE RESEARCH

In Search of Memory also describes many additional instances of neuroscience research in which behavior analysts could contribute by assisting in the analysis and specification of the behavioral contingencies. Examples are research on neuronal activity during delay periods between stimulus events as in the experiments on working memory by Goldman-Rakic (1995a, 1995b), Kalenscher et al. (2005), Yarkoni, Braver, Gray, and Green (2005) and Kandel (p. 353), as well as in research on attention, automatization, and other behavioral phenomena often termed ''cognitive.'' Schaal (2003, p. 95) provides the example of research on the neuronal effects of stress, where specification of the behavioral contingencies that generate the presumed stress would always be critically important.

Another major opportunity for collaboration is provided by research on imitation and ''mirror neurons'' (Arbib, 2005; Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Ramachandran, 2000; Rizzolatti & Craighero, 2004). Kandel comments on the significance of this research as follows:

> Rizzolati … suggests that they (mirror neurons) provide the first insight into imitation, identification, empathy, and possibly the ability to mime vocalization. Vilayannur Ramachandran has found evidence of comparable neurons in the premotor cortex of people … one can see a whole new area of biology opening up, one that can give us a sense of what makes us social, communicating beings. An undertaking of this sort might not only discern factors that enable members of a cohesive group to recognize one another but also teach us something about the factors that give rise to tribalism, which is so often associated with fear, hatred, and intolerance of outsiders. (pp. 425–426)

Systematic behavioral contingency analysis can reveal many of an independent variable's detailed components that may be differentially correlated with neural effects, but that can easily escape attention. These can include the precise wording of the instructions, the subject's prediction and/or perception of the act's consequences and their attributes, the full specification of the effort level, duration, or repetitiveness of the subject's acts, and the subject's history regarding all of the above (Mechner, 2008b, pp. 40–43; Schlund & Cataldo, 2005). The methodology used in many neural correlate studies often leaves open the logical possibility that the same neural activation pattern could also be produced by variables other than the presumptive independent variable, including some of its incidental parameters. What is often lacking in such studies is the causative isomorphism and symmetry present in some of Kandel's work. Those are reasons why a behavioral contingency-based methodology would constitute a substantial advance over the generally used ''verbal instruction'' approach.

A further interesting opportunity to apply contingency analysis in specifying the independent variable is presented by research on the neural correlates of the behavioral phenomenon termed ''observing false belief'' (e.g., Grèzes, Frith, & Passingham, 2004; Saxe & Baron-Cohen, 2007;). In the behavioral contingency language, the core dynamic of observing another party's false belief would be codified simply as a party's perception of another party's misprediction of an act's consequence (Mechner, 2008b, p. 44). Again, the full analysis of this type of contingency would reveal the numerous associated variables and potential parameters that could play important roles.

Kandel also often stresses the importance of studying animal models of behavioral phe-

nomena and comparing human and animal results in the mapping of brain functions, especially for nonverbal types of behavior. This is another area in which collaboration involving the application of contingency analysis methodology could be very productive.

''TASTE'' AND DISCIPLINE BOUNDARIES

In describing his thought processes, Kandel discusses a rarely addressed attribute that distinguishes the major contributors to science from the mere practitioners, namely, keen judgment regarding the choice of problems to work on. He calls it ''taste'' (pp. 172–173). Though he never tells us directly how to recognize taste, he provides ostensible examples of it.

One technique he describes at several points is one that could be described as parsing the problem. Knowing that Eccles was able to produce only brief synaptic changes, Kandel concluded that synaptic changes lasting a lifetime must result from a different type of learning. This parsing of memory storage into short-term and long-term was the breakthrough that led to Kandel's eventual discovery of the different neural mechanisms for the two:

> I realized that I would need to reformulate Cajal's theory that learning modifies the strength of the synaptic connections between neurons. Cajal thought of learning as a single process… I realized that there are many different forms of learning produced by different patterns and combinations of stimuli and that these give rise two very different forms of memory storage. (p. 159)

Kandel also appears to associate ''taste'' with adventurousness and the disposition to seek challenges at the boundaries of disciplines:

> I think it is important to be bold, to tackle difficult problems, especially those that appear initially to be messy and unstructured. One should not be afraid to try new things, such as moving from one field to another or working at the boundaries of different disciplines, for it is at the borders that some of the most interesting problems reside. (p. 427)

APPLYING KANDEL'S HEURISTIC

Kandel provides many examples of his own application of his thought provoking heuristic within and beyond his own research work. His frequent references to his persistent interest in the biological basis for the distinction between conscious and unconscious behavioral phenomena (e.g., pp. 370–375) reveal the continuing influence of his original training as a Freudian psychoanalyst. For example, he expresses fascination with Francis Crick's hypothesis that the claustrum may be the neural structure that mediates consciousness, though he leaves open the possibility that parsing this concept into observable behavioral phenomena would increase its susceptibility to experimental attack (pp. 383–384). He speculates that at the neural level, the phenomenon of consciousness may involve the fusion of multiple inputs by mechanisms analogous to the modulatory multisensory inputs to the hippocampus in the dopamine-dependent encoding of spatial environments, in this case also with directed attention functioning as the necessary spotlight and filter (pp. 307–315), (and as in Wurtz, Goldberg & Robinson, 1982).

Kandel's provocative heuristic may also challenge some behavior analysts to think of exciting research problems that reside at discipline boundaries. Here are two that occurred to me:

1. It is well established that when mistakes of any kind are learned and practiced, they may later resurge unexpectedly, and may interfere with the subsequent learning of more desirable behavior patterns (Mechner, 1992, pp. 49–61). This may be explained in part by Kandel's discovery that learning and the formation of long-term memories involves new growth at synapses. Kleim et al. (2002) found that in the absence of reinforcement of a learned reaching response, the number of synapses per cell declined. Are there types of interventions that reverse the neural growths that encode undesired long-term memory?
2. At the moment an imitation or mirroring act occurs, the model is no longer present — it was necessarily perceived prior to the act. Therefore, what is matched at the moment the imitation behavior occurs is the short-term or long-term memory of the model, whether it is called a representation, an image, or an internalized model

(Mechner, 1992, pp. 28–36). How is the mirror neuron system involved in the behavior of comparing, critiquing, and adjusting when matching a model during the activity of practicing a performance?

KANDEL'S REDUCTIONISM

Kandel makes repeated references to his ''reductionist approach'' and orientation. The examples he cites suggest that he uses the term in the sense of the direction in which he is inclined to look for questions and answers—the type of reductionism Mayr (1982) might call ''constitutive''—the view that any event or process consists of events and processes found at lower levels of analysis. Here are some examples:

> I was convinced that the biological basis of learning should be studied first at the level of individual cells, and moreover, that the approach was most likely to succeed if it focused on the simplest behavior of a simple animal … It seemed likely to me that, in the course of evolution, humans had retained some of the cellular mechanisms of learning and memory storage found in simpler animals. (p. 144)

> First, instead of conducting experiments in whole animals, I would remove the nervous system and work on a single ganglion … Second, I would select a single nerve cell—a target cell—in that ganglion to serve as a model … I would then apply different patterns of electrical pulses modeled on the different forms of learning to a particular bundle of axons extending from sensory neurons on *Aplysia*'s body surface to the target cell. (p. 161)

> In 1980 we carried our reductionist approach one step further and explored what happens at the synapses during classical conditioning. (p. 201)

> Our finding that short-term memory results from a functional change and long-term memory from an anatomical change raised even more questions. What is the nature of memory consolidation? Why does it require the synthesis of new protein? To find out, we would have to move into the cell and study its molecular makeup. (p. 218)

The ways in which Kandel applies the term *reductionist* to his research strategies suggest that he would agree with Gordon Shepherd that

> in order to understand how (e.g., the behavior of reading this page) occurs, we need to look inside the brain …To understand how a system works, we need to analyze the organization of the centers… one starts with a given behavior and works downward, so to speak, through successive levels of organization, to identify the units of function underlying that behavior. Nothing in neurobiology makes sense except in the light of behavior. (Shepherd, 1988, pp. 6–7)

In fact, Kandel's whole life story chronicles his inclination to seek understanding by ''looking downward.'' Having been victimized by the Nazis as a child, Kandel later undertook a historical analysis of Nazism,[8] and then proceeded down the explanatory hierarchy to psychoanalysis and the mind, medical school, study of the brain, and his receptivity to Harry Grundfest's comment that mind must be studied one brain cell at a time (p. 55). Kandel often also adopts the alternative bottom-up perspective, as when he writes, ''Cellular studies have provided the first glimpse into the biological basis of perception, voluntary movement, attention, learning, and memory storage'' (p. 59), and ''Each perception and thought we have, each movement we make, is the outcome of a vast multitude of basically simple neural calculations.'' (p. 72). Bottom-up and top-down accounts are often intertranslatable without introducing any new propositions or assertions, for example ''new synaptic growth accounts for long-term memory'' and ''long-term memory requires new synaptic growth.'' Kandel views the discoveries of neural science not as explanations of behavior, but rather as amplifying what is known about behavior, as a synthesis of levels of analysis.

LEADS FOR IDENTIFYING AND PRODUCING GOOD SCIENTISTS

I now return to the observation that case histories like *In Search of Memory*, when sufficiently detailed, can increase our understanding of what good scientists do. Marr

[8] He intersperses interesting references to that aspect of his story, including a perspicacious analysis of that historic episode.

(2003b, p. 65) points out that ''the science of behavior has given little attention to the behavior of scientists. Considering the complexity of the topic, this should not be surprising.''

> Scientific thinking is the most complex and probably the most subtle of all human activities… we do not know enough about human behavior to know how the scientist does what he does… Meanwhile, we can only fall back on examples. (Skinner, 1956)

Because the way good scientists do their work is as diverse as the problems they address, specific experiments can rarely serve as valid or typical examples of the supposed behavior of good scientists, much less of applications of the ''scientific method'' as described by the philosophers or statisticians. We need case history data to help us learn to identify behavior patterns that *all* good scientists share. While it may be easy to recognize a good scientist retrospectively, the challenge is to predict and control who might become one.

LONG-TERM IMMERSION

Marr (2003a, p. 23) makes the point that a behavioral characteristic seen in virtually all biographies of history's great achievers is long-term deep immersion in their craft. Kandel's account of his work illustrates this pattern repeatedly. Some corroborative quotations by others: Sir Isaac Newton—''I keep the subject of my inquiry constantly before me.'' Albert Einstein—''Mastery demands all of a person.'' Alexander Hamilton—''When I have a subject in hand, I study it profoundly. Day and night it is before me. My mind becomes pervaded with it.'' In the realms of music and painting too, the great ones—Bach, Mozart, Schubert, Beethoven, Monet, Van Gogh—all tended to work many hours per day almost every day for large periods of their lives, and generated the highest outputs per year compared to other composers and painters.

TENACITY AND OBSESSIVE PURSUIT OF A GOAL

A second, closely related behavior pattern that Kandel describes and that is also often seen in other biographies and case histories is the single-minded, tenacious, obsessive, long-term pursuit of a goal. Kandel spent the better part of a lifetime pursuing the goal of discovering the neurological mechanisms of learning and long-term memory, and some of those years in an intense search for the best research preparation, culminating in his choice of the giant sea snail *Aplysia*.

Whether the goal is the description of the genetic code, of the origin of species, of the laws of motion, or of a general theory of relativity, or the rendering of certain aesthetic color effects in painting light, these and innumerable other great achievements resulted from an intense, long-term, unswerving commitment to their pursuit. Some corroborative quotes: Louis Pasteur—''My strength lies solely in my tenacity.'' Albert Einstein—''It's not that I'm so smart, it's that I stay with problems longer.''

CONTRARINESS

In Search of Memory, like the biographies of virtually all great achievers, reveals a disposition, variously called contrariness, originality, unconventionality, rebelliousness, or anti-authoritarianism, to swim against the current of contemporary fashions and belief systems, and to question or even defy authority. The names of Galileo, Tycho Brahe, Copernicus, Lavoisier, Darwin, Pasteur, Einstein, Picasso, Cézanne, Beethoven and Stravinsky are prominent among those we associate with the disposition to buck the prevailing order, whether religious, cultural, scientific, or artistic. This trait may also be related to behavior variability and the disposition to generate accidents that provide opportunities for creativity (Skinner 1956; Marr, 2003a, pp. 18–20; Neuringer, 2003). Einstein, who often claimed contempt for authority, wrote ''The important thing is not to stop questioning.'' Here is one of many quotes from Kandel that make a similar point: ''Even though it meant swimming against the tide of current thinking, I yearned for a more radical, reductionist approach to the biology of learning and memory storage.'' (p. 144).

OPERATIVE REINFORCERS

Marr (2003a, p. 26) states that extrinsic reinforcers are often important in the motivations of great achievers, observing that for Newton and Ramanujan religious and mystical

motivations played a big role. Kandel makes frequent reference to the social and collegial rewards of scientific research and discovery.

But there is a particularly powerful and seemingly universal type of extrinsic reinforcer, a socially and interpersonally mediated one, on which virtually all great achievers, in all domains of human endeavor, appear to be highly dependent. It is variously called recognition, admiration, esteem, veneration, adulation, fame, prestige, power, influence, or credit. James Watson (1968) provides perhaps the most explicit and unabashed examples of the operation of this type of reinforcer among scientists.

Kandel claims no exemption for himself from susceptibility to such extrinsic reinforcers. He points with muted pride to his own intellectual and cultural heritage—the pre-World War II Viennese culture that spawned the Vienna Circle, the Ernst Mach Society, and the culture that was, in his words, ''a world center of scientific medicine, psychoanalysis … literature, science, music, architecture, philosophy, and art.'' Always straining not to cross the bounds of proper modesty, he describes, with evident relish, his impressive accomplishments and their culmination in his receipt of the Nobel Prize with its associated ceremony, as well as the world-wide acclaim he has been enjoying.

CURIOSITY

The capacity to be excited by ideas and discovery (e.g., Sidman, 2007; Skinner, 1956, 1972) seems to be a special behavioral trait associated with great achievers. About Cajal, Kandel writes: ''Santiago Ramon y Cajal … arguably the most important brain scientist who ever lived … was driven by the same curiosity that drove Freud and that many years later drove me.'' (p. 61).

Kandel's account of his own work pulsates with expressions of exhilaration, excitement, and wonderment: ''… I found the bang! bang! bang! of action potentials intoxicating. The idea that I had successfully impaled an axon and was actually listening in on the brain of the crayfish as it conveyed messages seemed marvelously intimate.'' (p. 108).

In describing his work on the hippocampus, he writes:

> Suddenly we heard the loud bang! bang! bang! of action potentials, a sound I recognized immediately from my experiments on crayfish. Alden had penetrated a cell! We quickly realized it was a pyramidal cell … every stimulus I applied elicited a beautiful, large action potential … Alden and I were euphoric — we had obtained the first intracellular signals ever recorded from the region of the brain that stores our fondest memories! We almost danced around the lab. (p. 139)

Einstein said, ''I have no special gift. I am only passionately curious.'' Richard Feynman (Feynman, 1999; Feynman & Leighton, 1988; Feynman, Leighton, & Hutchings, 1985) chronicled his raging curiosity regarding the natural universe.

SELECTING AND MENTORING

But the five behavior patterns and dispositions described above — let's call them long-term immersion, tenacity, contrariness, ego, and curiosity — are common to all great achievers, whether their pursuit consists of trying to reach the South Pole, winning military battles, becoming world chess champion, writing *The Ring of the Nibelung*, determining the mass of the electron, proving Fermat's theorem, or gaining political power. They are not specific or limited to the behavior of good scientists. An individual who rates high in all five could just as easily become a successful corporate CEO, business entrepreneur, journalist, or movie star.

An understanding of these five patterns may help us recognize them, but it does not help us teach them or acquire them. So how can we steer into science an individual whom we recognize as rating high in all five? That's where mentoring comes in. Kandel's story is replete with instances in which he was inspired, mentored, and taught by teachers and colleagues: ''I learned methodology and strategy from Grundfest and Purpura, and later from Stanley Crain … these early positive research experiences and the ideas to which I was exposed when I was twenty-five years old had a major impact on my thinking and life's work … I was beginning to think like a biologist.'' (p. 106).

Kandel relates how he subsequently learned from Alden Spencer's ''insights into what questions were scientifically important'' (p.

138) and the pivotal roles that Wade Marshall, James Schwartz, Richard Axel, and Steven Kuffler played in his scientific development. Like Kandel, most of history's great achievers owed their directions to mentoring: Alexander had Aristotle, Leonardo da Vinci had Andrea del Veroccio, Mozart had his father, Darwin had Lyell, and Einstein had his uncle Caesar.

In short, I recommend *In Search of Memory* as a ''must read'' for every behavior analyst — whether their primary interest is in advancing their science, in understanding and teaching it, or in applying its fruits.

REFERENCES

Arbib, M. A. (2005). The mirror system hypothesis: How did protolanguage evolve? In M. Tallerman (Ed.), *Language origins: Perspectives on evolution*, New York: Oxford University Press.

Bennett, M. R., Dennett, D., Hacker, P. M. S., & Searle, J. (2007). *Neuroscience and philosophy: Brain, mind and language*. New York: Columbia University Press.

Bennett, M. R., & Hacker, P. M. S. (2003). *Philosophical foundations of neuroscience*. Oxford, England: Blackwell Publishing.

Blakemore, C. (1990). Understanding images in the brain. In H. Barlow, C. Blakemore, & M. Weston-Smith (Eds.), *Images and understanding*, Cambridge, MA: Cambridge University Press.

Calvo-Merino, B., Glaser, D. E., Grèzes, J., Passingham, R. E., & Haggard, P. (2005). Action observation and acquired motor skills: An fMRI study with expert dancers. *Cerebral Cortex*, *15*, 1243–1249.

Cross, T. (2005). What is a disposition? *Synthese*, *144*, 21–341.

Dickins, D. W. (2005). On aims and methods in the neuroimaging of derived relations. *Journal of the Experimental Analysis of Behavior*, *84*, 453–483.

Donahoe, J. W. (2003). Selectionism. In K. A. Lattal, & P. N. Chase (Eds.), *Behavior theory and philosophy*, New York: Kluwer Academic/Plenum Publishers.

Eichenbaum, H., & Fortin, N. J. (2005). Bridging the gap between brain and behavior: Cognitive and neural mechanisms of episodic memory. *Journal of the Experimental Analysis of Behavior*, *84*, 619–629.

Feynman, R. (1999). *The meaning of it all: Thoughts of a citizen scientist*. New York: Perseus Publishing.

Feynman, R., & Leighton, R. (1988). *What do you care what other people think*. New York: W.W. Norton.

Feynman, R., Leighton, R., & Hutchings, E. (1985). *Surely you're joking, Mr. Feynman*. New York: W.W. Norton.

Freud, S. (1922). *Beyond the pleasure principle*. London, England: The International Psycho-Analytical Press.

Goldman-Rakic, P. S. (1995a). Architecture of the prefrontal cortex and the central executive. In J. Grafman, K. J. Holyoak, & F. Boller (Eds.), *Structure and functions of the human prefrontal cortex*, New York: New York Academy of Sciences.

Goldman-Rakic, P. S. (1995b). Toward a circuit model of working memory and the guidance of voluntary motor action. In J. C. Houk, J. L. Davis, & D. G. Beiser (Eds.), *Models of information processing in the basal ganglia*, Cambridge, MA: The MIT Press.

Gonzalez-Marquez, M., Mittelberg, I., Coulson, S., & Spivey, M. J. (Eds.) (2007), *Methods in cognitive linguistics*. Amsterdam, Netherlands: John Benjamins Publishing Company.

Green, L. (2006). Stasis and change. *Journal of the Experimental Analysis of Behavior*, *85*, 1–2.

Grèzes, J., Frith, C. D., & Passingham, R. E. (2004). Inferring false beliefs from the actions of oneself and others: an fMRI study. *NeuroImage*, *21*, 744–750.

Hefferline, R. F., & Keenan, B. (1963). Amplitude-induction gradient of a small-scale (covert) operant. *Journal of the Experimental Analysis of Behavior*, *6*, 307–315.

Jacobson, E. (1932). The electrophysiology of mental activities. *American Journal of Psychology*, *44*, 677–694.

Kalenscher, T., Güntürkün, O., Calabrese, P., Gehlen, W., Kalt, T., & Diekamp, B. (2005). Neural correlates of a default response in a delayed go/no-go task. *Journal of the Experimental Analysis of Behavior*, *84*, 521–535.

Kandel, E. R. (2006). *In search of memory: The emergence of a new science of mind*. New York: W.W. Norton and Company.

Kleim, J. A., Barbay, S., Cooper, N. R., Hogg, T. M., Reidel, C. N., Remple, M. S., & Nudo, R. J. (2002). Motor learning-dependent synaptogenesis is localized to functionally reorganized motor cortex. *Neurobiology Learning and Memory*, *88*, 63–77.

Kohler, A. (2003). Wittgenstein meets neuroscience: A review of *Philosophical foundations of neuroscience* by M. R. Bennett and P. M. S. Hacker. *Human Nature Review*, *3*, 459–460.

Mach, E. (1914/1959). *The analysis of sensations, and the relation of the physical to the psychical*. New York: Dover Publications.

Marr, M. J. (2003a). The stitching and the unstitching: What can behavior analysis have to say about creativity? *The Behavior Analyst*, *26*, 15–27.

Marr, M. J. (2003b). Empiricism. In K. A. Lattal, & P. N. Chase (Eds.), *Behavior theory and philosophy*, New York: Kluwer Academic/Plenum Publishers.

Mayr, E. (1982). *The growth of biological thought*. Cambridge, MA: Belknap Press.

Mechner, F. (1992). Learning and practicing skilled performance. At http://mechnerfoundation.org/newsite/downloads.html

Mechner, F. (2008a). Behavioral contingency analysis. *Behavioural Processes*, *78*, 124–144.

Mechner, F. (2008b). Applications of the language for codifying behavioral contingencies. At http://mechnerfoundation.org/newsite/downloads.html

Mechner, F. (2008c). Summary of neuroscence information in *In Search of Memory* by Eric R.Kandel. At http://mechnerfoundation.org/newsite/downloads.html

Moore, J. (2008). Conceptual foundations of radical behaviorism. *The Cambridge Center-Sloan Century Series in Behavior Analysis*. Cornwall-on-Hudson, NY: Sloan Publishing.

Neuringer, A. (2003). Creativity and reinforced variability. In K. A. Lattal, & P. N. Chase (Eds.), *Behavior theory and philosophy*, New York: Kluwer Academic/Plenum Publishers.

O'Keefe, J., & Dostrovsky, J. (1971). The hippocampus and as a spatial map: Preliminary evidence from unit activity in the freely-moving rat. *Brain Research, 334, No. 1*, 171–175.

Palmer, D. (2003). Cognition. In K. A. Lattal, & P. N. Chase (Eds.), *Behavior theory and philosophy*. New York: Kluwer Academic/Plenum Publishers.

Ramachandran, V. S. (2000). Mirror neurons and imitation learning as the driving force behind ''the great leap forward'' in human evolution. At http://www.edge.org/3rd_culture/ramachandran/ramachandran_p1.html.

Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annual Review of Neuroscience, 27*, 169–192.

Ryle, G. (1949). *The concept of mind*. Chicago: The University of Chicago Press.

Saxe, R., & Baron-Cohen, S. (Eds.) (2007), *Theory of mind: A special issue of social neuroscience*. London: Psychology Press.

Schaal, D. W. (2003). Explanatory reductionism in behavior analysis. In K. A. Lattal, & P. N. Chase (Eds.), *Behavior theory and philosophy*. New York: Kluwer Academic/Plenum Publishers.

Schaal, D. W. (2005). Naming our concerns about neuroscience: A review of Bennett and Hacker's *Philosophical Foundations of Neuroscience*. *Journal of the Experimental Analysis of Behavior, 84*, 683–692.

Schlund, M. W., & Cataldo, M. F. (2005). Integrating functional neuroimaging and human operant research: Brain activation correlated with presentation of discriminative stimuli. *Journal of the Experimental Analysis of Behavior, 84*, 505–519.

Shepherd, G. M. (1988). *Neurobiology (2nd ed.)*. New York: Oxford University Press.

Sidman, M. (2007). The analysis of behavior: What's in it for us? *Journal of the Experimental Analysis of Behavior, 87*, 309–316.

Skinner, B. F. (1938). *The behavior of organisms*. New York: Appleton-Century-Crofts.

Skinner, B. F. (1950). Are theories of learning necessary? *Psychological Review, 57*, 193–216.

Skinner, B. F. (1953). *Science and human behavior*. New York: The Macmillan Company.

Skinner, B. F. (1956). A case history in scientific method. *American Psychologist, 11*, 221–233.

Skinner, B. F. (1957). *Verbal behavior*. New York: Appleton-Century-Crofts.

Skinner, B. F. (1972). *Cumulative record*. New York: Appleton-Century-Crofts.

Skinner, B. F. (1974). *About behaviorism*. New York: Alfred A. Knopf.

Sytsma, J. M. (2007a). Language police running amok. *Journal of Theoretical and Philosophical Psychology, 27*, 89–103.

Sytsma, J. M. (2007b). The proper province of philosophy: Ordinary language meets experimental philosophy. At http://philsci-archive.pitt.edu/archive/00003471/01/The_Proper_Province.doc

Timberlake, W., Schaal, D. W., & Steinmetz, J. E. (2005). Relating behavior and neuroscience: Introduction and synopsis. *Journal of the Experimental Analysis of Behavior, 84*, 305–311.

Thompson, T. (2007). Relations among functional systems in behavior analysis. *Journal of the Experimental Analysis of Behavior, 87*, 423–440.

Watson, J. (1968). *The double helix: A personal account of the discovery of the structure of DNA*. New York: Athenaeum.

Wurtz, R. H., Goldberg, M. E., & Robinson, D. L. (1982). Brain mechanisms of visual attention. *Scientific American, 246*, 124–135.

Yarkoni, T., Braver, T. S., Gray, J. R., & Green, L. (2005). Prefrontal brain activity predicts temporally extended decision-making behavior. *Journal of the Experimental Analysis of Behavior, 84*, 537–554.

APPENDIX

Below is a brief synopsis of some highlights of what Kandel and his colleagues have discovered. For a more detailed summary see Mechner (2008c).

> Neurons that mediate between sensory and motor neurons release glutamate into a synapse. The amount of glutamate they release, and the consequent strength of synaptic transmission, is tuned by the release of serotonin by modulatory interneurons at the mediating neuron's membrane. The momentary release of serotonin triggers the production, inside the mediating neuron, of cyclic AMP which sets in motion a chain of chemical reactions. The resulting synaptic events last only minutes. But the conversion of a short-term into a long-term memory requires the growth of new terminals at the same synapse. The frequency, intensity, or number of repetitions of the impulses from the modulatory interneurons determines the amount of new growth and consequently the length of time the memory will last.
>
> The new growth involves protein synthesis (as all growth does), which in turn requires the creation of RNA templates. *How this happens:* As the modulatory interneurons provide sufficient stimulation of the mediating neuron, genes in the mediating neuron's nucleus are activated with resulting creation of messenger RNA and the manufacture (in the neuron's ribosomes) of the proteins from which the new terminals are built. The messenger RNA for manufacturing the proteins for new growth is sent to all of the neuron's synaptic terminals, of which there may be thousands, but protein synthesis occurs only at those terminals that are ''marked for growth'' by the modulatory interneuron's serotonin stimulation. But the protein synthesis process quickly fizzles if it is not maintained so as to complete the new growth and create the long-term memory, and it is maintained only at the marked terminals.
>
> These mechanisms describe learning and memory formation in the sea snail *Aplysia*, and long-term potentiation in the mammalian

brain differs from it in some respects, but is substantially similar. In the mammalian brain, modulatory neurons also often release dopamine (which is also associated with reinforcement and attention). Like serotonin in other neural circuits, dopamine can stimulate the activation of cyclic AMP, which initiates the sequence of events that culminates in the turning on of genes that produce new growth.