Debate on Learning Theory Is Shifting

Though many psychologists and ethologists now agree on using a mechanistic approach, some linguists doubt its adequacy

From the lowly mollusks up to man, the cellular machinery of the nervous system is remarkably consistent. Does that consistency imply that learning, however it occurs, obeys common rules and mechanisms? If so, what accounts for the wide differences in learning abilities among species, apart from obvious differences in brain size? Can subtle differences in machinery account for huge differences in learning capability?

On these questions and the corollary issues they raise, an old debate is reshaping. It sometimes has been centered between learning theorists (psychologists), who sought general themes to describe how animals learn, and ethologists, whose field studies in natural surroundings led them to see laboratory studies and the theories derived from them as being artificially constrained. More recently, however, the center of that debate has shifted.

The sharpest division now is between those who contend that knowing all there is to know about the brain's machinery could prove irrelevant for settling the debate—and virtually everyone else. This first group now argues that the empirical approach to studying the brain results in mere tinkering with the problem of human learning, especially the language capacity, and is not rich enough to provide meaningful solutions.

Though learning theory was conceived as a way to formulate all animal learning behaviors within a simple set of principles, it has become considerably particularized, if not fragmented, during the past two decades. And what once was regarded with "high optimism," according to Harvard psychologist William Estes, has since been replaced by "strong disillusionment." Ethologists played a large part in causing that fragmentation, by forcing psychologists to consider how animals behave in more natural settings where laboratory-defined rules for learning can take on different appearances. But the dismantling of an over-arching learning theory also came from within the animal psychologists' framework, where seeming principles established in one setting could not easily be made to fit another, thus forcing theorists to limit their generalizations accordingly.

Nevertheless, in the absence of a general theory for learning, psychologists along with other biologists interested in cognitive processes do not hesitate to invoke other biological theories, particularly evolutionary theory, to explain—or explain away—various findings. This reliance on the theory of evolution can lead to some wild guesses about the meaning of field or experimental observations.

Those surmises can be wielded with surprising certitude on occasion. For example, during a recent workshop* one psycholinguist casually but emphatically dismissed the process of birdsong acquisition as irrelevant to human language acquisition, arguing that any mechanistic similarities that might be found between the two processes must be due to convergent evolution, therefore merely accidental, and unworthy of deep consideration. He may be correct, but his reliance on evolutionary theory leads to a peremptory approach to comparative biology.

> Fitting *Aplysia* into learning theory would not account for human behavior in terms we really want . . .

At another extreme, many scientists who study learning seem increasingly inclined to ignore theory and, instead, embrace the approach of the neuroscientists. This latter rests on describing the structure, chemistry, and physiology of the nervous system as a way of divining its higher principles. Though growing steadily, faith in this reductionist approach is by no means universal. For example, several scientists at the workshop, who are interested in language acquisition, asserted that there is little correspondence between various models for how learning occurs and what is known of the underlying biology. Especially in cases of language relearning for patients with aphasia, they note, "A particular functional unit may or may not correspond to a particular anatomical locus." Or, to paraphrase the more graphic terms employed by one learning theorist, "The brain could be a bowl of porridge so far as I'm concerned."

This view is not intended to discredit the neuroscientists' contributions so much as to question whether they can provide a rich enough theoretical base for describing and understanding learning. Such skepticism from various quarters, however, does not keep the neuroscientists from forging ahead and making enough progress to impress many psychologists and ethologists. The greatest successes are being registered by studying some of the simplest members of the animal kingdom, such as the sea mollusk *Aplysia*, championed for some years now by Eric Kandel of Columbia University and his many collaborators. Other invertebrates, including other mollusks (such as *Hermissenda*), a slug (*Limax*), the fruit fly (*Drosophila*), and various species of bee also are being studied. When their behavior conforms to some of the rules formulated by learning theorists, this is seen as an encouraging countervailing force against the fragmentation of learning theory.

Though no genius, *Aplysia* can learn in the same sense that the Pavlov dog learns to salivate when a bell rings. The mollusk displays two forms of modifiable behavior: When its siphon is touched repeatedly, its reflex withdrawal of that organ wanes ("habituates" is the term used by psychologists). That same withdrawal response becomes accentuated ("sensitized") when the animal is given a mild electric shock in its tail. An example of associative learning occurs when an animal is touched lightly at two different sites, with one of those stimuli administered along with a mild shock, the other not. Later, touching the animal at the site that was matched up with the shock elicits a much greater siphon withdrawal response than does touching the other site.

"We've focused on one aspect, the way animals connect two stimuli separated in time," says Kandel's former collaborator Thomas Carew, who now is at Yale University. Because *Aplysia* is such a simple organism, it's possible to study at the cellular level changes that

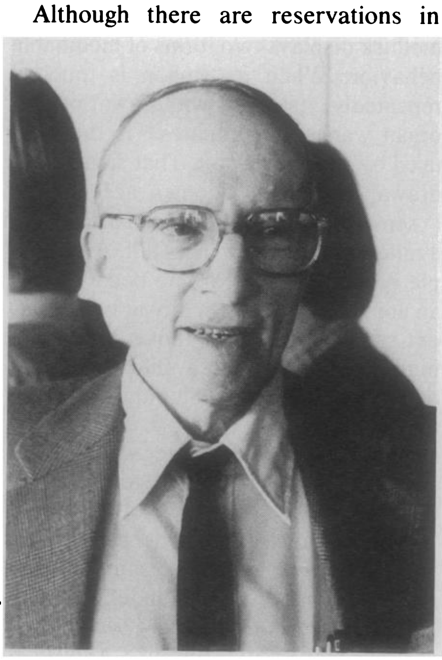
*Dahlem Workshop, "The Biology of Learning," Berlin, 23 to 28 October 1983.

accompany the behavioral modifications. Several rules thus are established, according to Kandel and another collaborator, Robert D. Hawkins. This kind of learning is localized in specific nerve cells; it produces changes in membrane properties in synapses between nerve cells; and those changes consist not in the laying down of new synapses but in the modulation of existing ones, a phenomenon whose chemistry is being studied in considerable detail.

It is tempting to accept this mechanism and apply it to other instances of learning willy-nilly. The rich details of the chemistry involved are in many ways consonant with that found in other nervous systems. Nonetheless, chemical discrepancies can be identified between one system and the next. And from a psychologist's perspective, *Aplysia* does not seem to account for all, and perhaps not for many, kinds of conditioning. One drawback is that these studies describe learning in terms of a "prewired" circuit that becomes appropriately strengthened or weakened.

In this vein, the *Aplysia*-based model suffers from providing a "local" instead of a "network" theory, according to William Quinn, a neurobiologist from Princeton University. The mollusk's simple learning behavior is furnishing insights into the learning problem at the level of single synapses. "The first problem is not solved but it is providing some building blocks," Quinn says. But regarding the second problem of building a theory to encompass networks, "We don't know how to deal with it, and we don't have deep solutions in sight," he adds.

Although there are reservations in some quarters about the general relevance of prewiring, the notion does lead to attractive models to account for learning. One of the most appealing, known as the neuroselection theory, has been developed by Jean-Pierre Changeux of Institut Pasteur in Paris.



Jeffrey Fox

William Estes

High optimism replaced by disillusionment.

At the core of Changeux's theory is the idea that the brain's early development results in ensembles of nerve cells. Learning through experience then becomes a way of changing those already wired ensembles and, more specifically, of choosing and selecting those that will become enhanced.

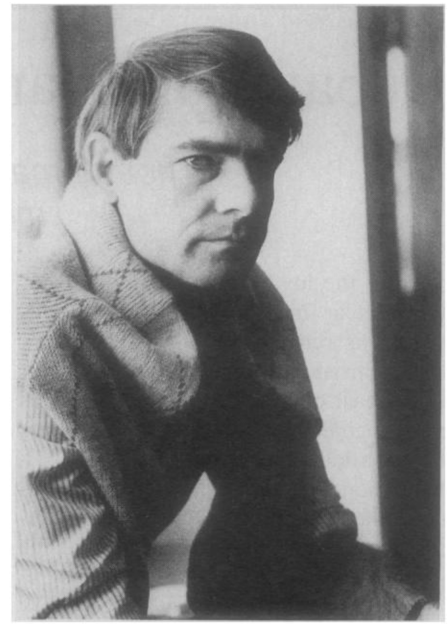
"Those assemblies can fire either in interactions with the outside world—percepts—or, endogenously, to give mental representations," Changeux says. The wiring of the system and its ability to reassociate freely and spontaneously may be all that's needed to create the diversity of connections deemed necessary to account for learning. But eventually that diversity must be pared down for learning to occur. For this, Changeux postulates a dynamic property of the nervous system that he calls "resonance." Qualitatively, resonance is defined as a mechanism for selecting and stabilizing some of these combinations.

The idea that sensory system stimuli can reinforce random firings of the brain by resonating with them has a certain intuitive appeal. However, it is not altogether easy to translate this idea into data. Nonetheless, Changeux's notions seem to hold up for some other less abstract, though still highly descriptive, examples of learning.

For instance, Wolf Singer of Max-Planck Institut für Hirnforschung in Frankfurt considers the visual system of the cat and monkeys in a way that, for purposes of discussion, equates adult learning processes with what occurs during embryologic development.

"Learning is the prolonging of a self-organizing process," Singer says. "If you look at a stage where the embryo is active, lots of neurons are hooked up, but then 'exuberant' hookups are removed, and this self-organizing is guided by neuronal activity." Before birth, the activity patterns in the brain begin a sorting out process in a relatively closed environment (uncontestably true for visual input). When the organism is born, it "keeps the same game going," Singer says, with a major difference being that new environmental stimuli are available to inform the process.

"The adaptive processes during early ontogeny—at least at this descriptive level—closely resemble what is usually termed associative learning," Singer



Wolf Singer

Learning: a self-organizing process.

points out. "Conversely, the adaptive processes in the adult brain, commonly described as 'learning' processes, might differ only quantitatively from the processes of self-organization occurring during ontogeny." He believes there is "neither a logical nor a factual argument against" learning being the "continuation of adaptive self-organization."

The closest parallel between development, such as occurs for the visual system, and learning involves the special form of learning called imprinting. Many scientists now contend that imprinting, though not identical to higher forms of learning, may be closer to them than originally believed. This initially modest comparison also forms a springboard for linking ontogenic development to still other forms of learning, such as song learning.

Classically, imprinting is the process whereby a young bird identifies and follows a parent figure. This learning is characterized by a degree of plasticity in that young birds can be fooled into following diverse incorrect figures, including people or inanimate objects.

Song learning and imprinting in birds share many features. Both depend on specialized regions of the brain remaining intact; both occur during particular time periods; both are valuable adaptive skills; and neither can be equated readily with what psychologists call classical conditioning. At one level, the debate over whether these processes are essentially the same as other forms of learning continues. Klaus Immelman of Universität Bielefeld, West Germany, says that the occurrence of imprinting-type learn-

Jean-Pierre Changeux

Resonance stabilizes nerve ensembles.

ing at a critical time is really its distinguishing characteristic. Moreover, because imprinting occurs early when the brain is developmentally more plastic, it may be the "type of information storage and not the kind of acquisition of such information which is different between . . . imprinting and 'other' learning processes."

At another level, scientists on either side of this debate argue that, regardless of its outcome, the imprinting mechanism may be of general interest. "Indeed, it would be surprising if an efficient means of storing information were used only for one kind of job and a quite different storage mechanism was used for others," says Patrick G. Bateson, of the University of Cambridge, England, who has gradually come to view imprinting as a special form of learning.

The fervor of this debate is nothing compared to that between psychologists and ethologists. But, at least in some circles, a rapprochement is under way, according to many scientists who attended the Dahlem workshop. The information developed by followers of these different disciplines, after all, "can't be entirely independent," Harvard's Estes points out. "A commonality is forced by the animals we've studied. And, one way or another, we're all interested in how this equipment works."

Beyond that, some psychologists now realize a need to understand an animal's learning behavior in a context more closely aligned to the one that animal sees naturally. For example, Karen Hollis of Mt. Holyoke College, South Hadley, Massachusetts, suggests that Pavlovian conditioning—one of the time-honored examples of anticipatory learning behavior accepted by learning psychologists—can be viewed usefully in an ethologist's context. Thus, she argues, such conditioning is a way in which animals cope with their natural habitat; it is literally and figuratively preparative behavior. Moreover, the search for biological function within such behaviors not only provides a convenient device for understanding a wide array of phenomena, it also "might further our understanding of mechanisms," Hollis contends.

Perhaps as important, observing how animals learn in their habitats has emphasized the complexity of the processes. "There is no such thing as THE bird brain," one wag put it. Popular notions notwithstanding, birds, bees, and other simple creatures are capable of relatively complex learning. For example, bees can learn where a food source is located merely by watching the dance of another bee. Though such communication cannot be equated with speech, it can be called "instructive learning"—occurring in an invertebrate species whose brain occupies 1 cubic millimeter of space.

And, to cite one other example, foraging birds somehow make useful, apparently sophisticated estimates of prey densities. "Foragers are not faced with a static environment," says Stephen Lea of the University of Exeter in England. "They may not know the prey density in an environmental patch, therefore they must learn it. And from estimates of prey density in the past, they know how to calculate the future and must know what to do with the estimate." The relevance of this learning capacity to the birds' survival is obvious.

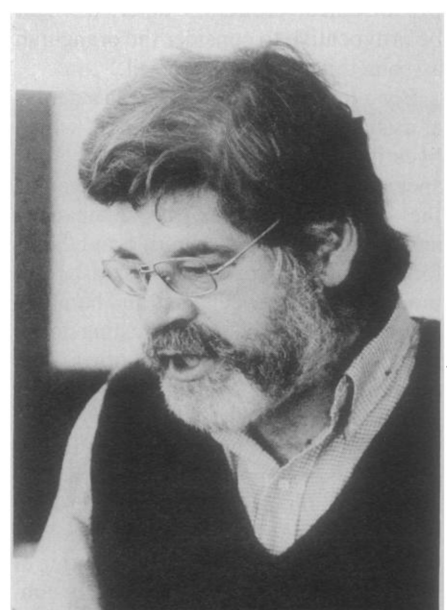
However, its relevance to what may well be the central debate among those who are concerned with learning theory is more philosophic, thus perhaps a bit obscure, but crucial in importance. No one disputes that the brains and learning capacity of birds—not to mention diverse other creatures—are remarkably complex. Hence Lea, along with many others, argues, "The only important cognitive difference within the vertebrates is the human capacity to learn language."

Language is the great dividing line between humans and other animals, and the sharpest debate centers on this intellectual capacity and how it meshes with learning theory. "Some of us question whether learning theory has any relevance to human behavior," says John Marshall, a neuropsychologist of the Radcliffe Infirmary, Oxford, England. "Short of toilet training, I couldn't come up with a human behavior that's like stimulus-response conditioning."

There are two principal and opposing theories to explain language. The cognitive model holds that language represents a complex solution to a set of communication problems that a human is faced with, and in solving that problem a host of general cognitive capacities (some of which may be uniquely human) are recruited. The other model, developed by Noam Chomsky of Massachusetts Institute of Technology, describes language metaphorically as an "organ" because the capacity is specialized, innate, automatic, and finite, in the sense that the underlying structures of human languages are remarkably similar and few in number despite their wide variety. In some respects, these qualities make human language seem like other specialized forms of learning, such as imprinting and song learning in birds, but it quickly becomes difficult to carry that comparison very far.

Language function is often studied by testing and observing patients who have suffered brain damage, become aphasic, and therefore must relearn former skills. But that relearning is neither qualitatively nor quantitatively "natural," according to Marshall and John Morton of the Medical Research Council's Cognitive Development Unit in London. "The overall pattern [of relearning] is consistent with the relevant skills being of a qualitatively different type from the original 'automatized' fluency."

Marshall and Morton cite findings of Jason Brown, neuropsychologist at New York University, showing that a "constant" lesion may change dramatically



Thomas Bever

Language is not pieces of real estate.

throughout the life-span of an individual. "What mechanisms . . . could account for such a progression? What kind of 'shifting' organ are we dealing with? . . . 'Decrease of plasticity' with age is a description of the phenomenon, not an explanation of the data," they argue. "[T]he anatomical integrity of functional units seems an irrelevant consideration."

Not everyone who sympathizes with the linguist's view of the brain agrees with Morton and Marshall about the irrelevance of neuroanatomy. "Structures that are revealed once they've become neurologically fixed won't necessarily identify what the original components of a skill were," says psycholinguist Thomas Bever of Columbia University, but structural studies "can tell us something of the capacity itself. I don't claim that components of the [language] module will be . . . particular pieces of neurological 'real estate'—[but] one intent is to create a theoretical psychology that will tell us where to go looking anatomically."

Marshall and Morton seem willing to concede that the learning behavior of simple organisms can be understood according to such rules: "[T]he relationship between learning theory and natural behavior is only to be determined through functional representations of what the organism's nervous system does, not what it is. With simple organisms, such as *Aplysia*, this relationship can most readily be established in terms of its neurophysiology and neurochemistry."

But beyond such concessions, they are not yet willing to move. "With humans it can at best only be done abstractly," they continue. "Thus, suppose it turned out that all human synapses were equivalent to *Aplysia*'s, and suppose that all the behavior of such a synapse were expressible in terms of learning theory. Suppose further that we had all the human neurobiological information there was to have. We might then have an account of natural human behavior and that account might be couchable in learning theoretic terms, but we would not have an explanation in terms of the questions we really wanted to ask."

—**Jeffrey L. Fox**

Is the Orangutan a Living Fossil?

Molecular biology and paleontology have combined recently to arrive at a consensus on human/ape evolution; a new Kenyan fossil stirs the debate once more

Earlier this year Richard Leakey, of the National Museums of Kenya, in company with Alan Walker of Johns Hopkins University, found upper and lower jaw fragments of an extinct ape about the size of a male chimpanzee that lived in northern Kenya about 17 million years ago. The discovery, made public at the beginning of December, adds a new and somewhat controversial element to the emerging view of human and ape origins over the past 20 million years. For instance, proffers Walker, it might be provocative to consider the orangutan as something of a living fossil.

For a long time there has been a general assumption that the orangutan, which lives in Asia, is evolutionarily the most specialized of the great apes, whereas the African great apes (the chimpanzee and gorilla) are more primitive and therefore resemble more closely the last common ancestor between apes and humans. "These fossils raise the interesting possibility that it might be the other way around," suggests Walker.

In addition to their evolutionary implication for modern great apes, the fossils may have an important bearing on estimating the time of divergence between the human line (hominids) and the African apes. This has long been a matter of much dispute but was until recently considered by most paleoanthropologists to be about 15 million years. Results from studies of proteins and DNA have for some time been taken by certain molecular biologists to imply a divergence date of 4 or 5 million years, a relatively recent split but one that paleoanthropologists have now begun to take seriously. The great age of the new Kenyan fossils, with their apparent affinity with the modern orangutan, might once again push back that all important date, to around 10 million years.

The modern apes are but a remnant of a once widespread and diverse group. The ape lineage appears to have arisen almost 30 million years ago and began to flourish in the tropical forests of Afro-Arabia. Although the fossil record of the Miocene epoch (25 to 5.5 million years ago) is at best spotty, it is clear that by 20 million years ago there were at least six species of the genus *Proconsul*, which group is considered a good bet as being ancestral to the living apes and hominids. Around 17 million years ago tectonic plate movement brought Afro-Arabia into contact with Eurasia, whereupon a great interchange of faunas occurred between the two landmasses. Apes took part in this interchange and proliferated greatly throughout southern Eurasia at a time when cooling global climates reduced much dense tropical forest to more open woodland.

Included in the great Miocene diversity of apes in Africa and Eurasia were two of especial interest: a small creature, named *Ramapithecus*, which for a long period was considered the best candidate as the first hominid; and a larger version, named *Sivapithecus*. Until recently, both these forms were known primarily from specimens of jaws and teeth.

The anatomical features that gave *Ramapithecus* its designation as probably the first hominid were its robust jaw and thick layer of enamel that capped its cheek teeth. *Ramapithecus* shares these with the later undoubted hominids, the australopithecines, the oldest known fossils of which date to almost 4 million years. Because there has always been a tendency to view hominid features as specialized and those of apes not, the robust jaw and thick enameled teeth of australopithecines were so classified. *Ramapithecus*, endowed with these same characteristics, was therefore also thought to be specialized and, because of its inferred small body size, was generally designated as the beginning of the human line. The age of known *Ramapithecus* fossils, which range from 8 million to 14 million years, provided the probable divergence time between hominids and the apes: 15 million years.

Modern human molar teeth have relatively thick enamel, which continues this supposed diagnostic trait. Chimpanzee and gorilla tooth enamel, by contrast, is thin. This appears to fit the inferred evolutionary pattern, with the great apes supposedly representing the primitive condition. Orangutans, however, disrupt