# The Mind and Donald O. Hebb

*By rooting behavior in ideas, and ideas in the brain, Hebb laid the groundwork for modern neuroscience. His theory prefigured computer models of neural networks*

by Peter M. Milner

Donald O. Hebb, one of the most influential psychologists of his time, began his adult life intending to be a novelist. Deciding that his calling required an understanding of psychology, he embarked on a course that led him into two decades of research. His studies culminated in 1949 with the publication of *The Organization of Behavior,* a keystone of modern neuroscience.

The monograph broke new ground by positing neural structures, called cell assemblies, which were formed through the action of what is now called the Hebb synapse. The cell-assembly theory guided Hebb's landmark experiments on the influence of early environment on adult intelligence. It foreshadowed neural network theory, an active line of research in artificial intelligence.

Hebb's book came at the right time because it flew in the face of behaviorism just as that school was losing its dominance. The behaviorists denounced explanations of behavior by association of ideas (which they called mentalism) and by the action of neurons (which they called physiologizing). But many psychologists had grown weary of the artificial theories these strictures had engendered, and they were captivated by Hebb's project and his engaging literary style. The book became a classic, and Hebb became a household word (at least in psychologists' households).

Hebb never claimed that his 1949 theory was firmly grounded in physiology. His model gave workers something to look for, and later, as knowledge of the brain grew, it became possible to frame his ideas in more realistic neural terms. None of this subsequent research has invalidated Hebb's basic hypothesis. Indeed, its influence appears in many areas of current research.

Hebb was born in Chester, a small fishing and boat-building town in Nova Scotia. His parents were physicians, and his two brothers and his sister followed in their parents' footsteps. But Donald demonstrated his independence early by studying English in preparation for a career as a writer, graduating in 1925 from Dalhousie University in Halifax. To earn his living while gestating his first novel, he taught school in his hometown. A year later he set out to see life, going west to work an eight-horse team on prairie farms. Then, failing to get a job as a deckhand on a freighter to China, he returned east and got a job as a laborer in Quebec.

In 1927 an aspiring novelist not only had to know life but also the works of Sigmund Freud. This was Hebb's introduction to psychology. He was sufficiently intrigued to apply to the psychology department of McGill University, where he was accepted in 1928 as a part-time graduate student. Again he supported himself by teaching and, again, what started out as a temporary interest verged on becoming a career. After one year he was made principal of an elementary school in a working-class district of Montreal. He was determined to make learning enjoyable, taking care to prevent schoolwork from being used as a punishment, instead sending miscreants out of class to play in the school yard. Hebb became absorbed in his educational experiments and seriously considered remaining in the profession. Two developments dissuaded him. He came down with a tubercular hip that confined him to bed for a year and left him with a slight limp. Then his bride of 18 months was killed in an automobile accident. He therefore decided to leave Montreal.

While confined to bed, Hebb wrote a master's thesis that involved him in the nature-nurture controversy. The thesis attempted to explain spinal reflexes as the result of Pavlovian conditioning in the fetus. He subsequently buried all references to this essay both because he changed his mind about its content and because he came to oppose psychological research that lacked an experimental foundation.

One of his examiners was Boris P. Babkin, a physiologist who had worked with Pavlov in St. Petersburg. He recommended that Hebb get some experience in the laboratory and arranged for him

**DONALD O. HEBB made his name as a theoretician but was equally distinguished as a teacher. Here he appears in a seminar held in the late 1960s.**

PETER M. MILNER is professor emeritus of psychology at McGill University. He received a B.Sc. in engineering from the University of Leeds in the U.K. in 1942 and was immediately recruited for radar research by the novelist C. P. Snow. "My first serious encounter with psychology followed soon afterward," he says, "while working on the interface between radar displays and the human visuomotor system." He later went to Canada to work on nuclear energy. In 1948 he left physics to take a Ph.D. in physiological psychology at McGill under the supervision of Donald O. Hebb. Milner is co-discoverer, with the late James Olds, of the reward mechanism in the brain and has written extensively on the system and its implications for theories of reinforcement and learning. He has also written a textbook on physiological psychology as well as papers on attention, visual recognition, memory and the mind-body problem.

to work with another Russian emigré, Leonid Andreyev. Hebb conditioned dogs and became less impressed with Pavlovian techniques. After much soul-searching as to whether he should continue in psychology, he decided in 1934 to burn his boats, borrow money and go to Chicago to continue his doctoral research under Karl S. Lashley.

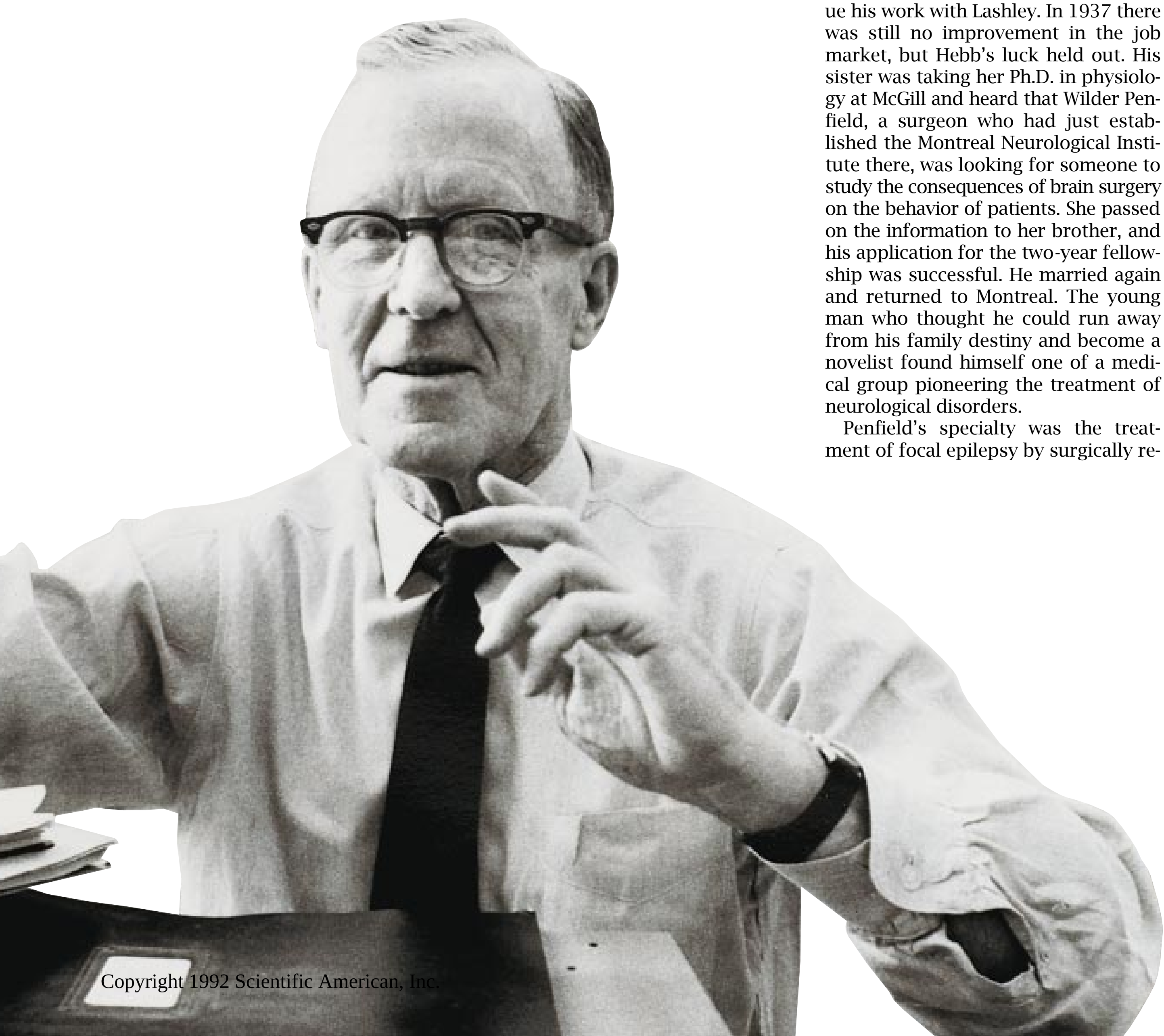
The elder scientist was to exert a profound influence on Hebb's approach, above all in his emphasis on physiology. Lashley had never doubted that to understand behavior one must first understand the brain. As a lab boy in 1910, he had salvaged slides of a frog brain from the trash heap and tried to find in the neural connections some clue to frog behavior. Lashley performed experiments to detect memory traces in the brain, inventing techniques for making brain lesions and measuring their location and extent. By around 1930 he had become convinced that memories could not be stored in a single region of the brain but must be spread throughout. In 1934, when Hebb went to Chicago, Lashley was concentrating on the study of vision.

A year later Lashley was offered a professorship at Harvard University and managed to take Hebb along. Hebb had to start his research from scratch, and having only enough money for one more year, he sought an experiment that could support a thesis no matter how it came out. He contrived to adapt his interest in the nature-nurture question to Lashley's vision project by investigating the effects of early experience on the development of vision in the rat.

Contrary to the empiricist ideas of his master's thesis, Hebb found that rats reared in complete darkness could distinguish the size and brightness of patterns as accurately as rats reared normally. This finding indicated that the organization of the visual system was innate and independent of environmental cues, a view coinciding with that of the Gestalt school, to which Lashley was sympathetic [see "The Legacy of Gestalt Psychology," by Irvin Rock and Stephen Palmer; SCIENTIFIC AMERICAN, December 1990]. What Hebb did not notice, although the results were included in a paper he published at the time, was that the dark-reared rats took much longer than normal rats to learn to distinguish vertical from horizontal lines. Only many years later, after he had again changed his ideas about the relative importance of innate and learned mechanisms, did he appreciate the significance of this result.

Hebb received his Ph.D. from Harvard in the middle of the Depression, when there were no jobs in physiological psychology to be had. He therefore stayed on for a year as a teaching assistant, a post that enabled him to continue his work with Lashley. In 1937 there was still no improvement in the job market, but Hebb's luck held out. His sister was taking her Ph.D. in physiology at McGill and heard that Wilder Penfield, a surgeon who had just established the Montreal Neurological Institute there, was looking for someone to study the consequences of brain surgery on the behavior of patients. She passed on the information to her brother, and his application for the two-year fellowship was successful. He married again and returned to Montreal. The young man who thought he could run away from his family destiny and become a novelist found himself one of a medical group pioneering the treatment of neurological disorders.

Penfield's specialty was the treatment of focal epilepsy by surgically re-



moving scarred areas of the cerebral cortex. He was acutely aware that he was operating on the organ of the mind and that a false move could deprive his patient of speech, intelligent behavior or even consciousness. Although Penfield was not a psychologist, his work exposed him to the relation between the mind and the nervous system. This experience no doubt influenced his decision to appoint psychologists to his team and explained the close interest he took in their findings.

Hebb's main responsibility was to study the nature and extent of any intellectual changes in patients consequent to cortical excisions. Such research was not new: it began after World War I with the psychometric testing of soldiers who had suffered penetrating head wounds and continued later in patients with brain tumors. In many cases, the lesions produced significant intellectual loss, but their locus and extent were difficult to determine. In contrast, surgical removals are more precisely defined, and epileptic scars do not cause the widespread damage that bullets or tumors do.

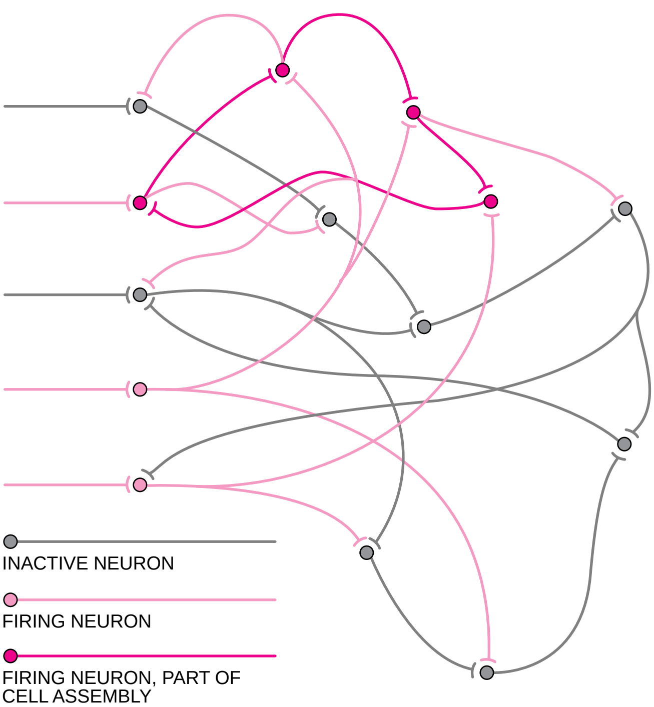
Hebb soon faced a peculiar problem. Psychologists then regarded the frontal lobes of the cerebral cortex as the seat of human intelligence, on the grounds that this region is relatively much larger than the corresponding areas in less intelligent animals. Yet Hebb was not able to detect intellectual loss in patients whose frontal lobes had been destroyed by accident or surgical necessity. This seeming lack of effect impressed Hebb deeply and inspired his quest for a theory of the brain and intelligent behavior.

Although his observations set him off on fruitful lines of inquiry, later work showed that Hebb had relied too heavily on standard intelligence tests. Brenda Milner, one of his students, who continued the work he had begun on Penfield's patients, found that frontal-lobe lesions often make it difficult for the patient to relinquish a behavior that has ceased to be appropriate. Although they may not be detected by intelligence tests, personality changes after frontal-lobe damage can profoundly affect the patient's life.

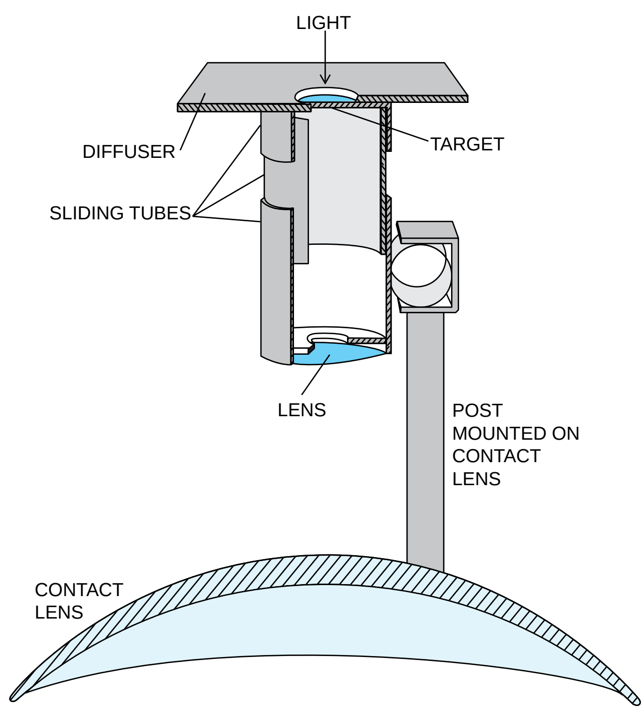
At the end of his fellowship at the neurological institute, Hebb finally found a permanent job at Queen's University in Kingston, Ontario. There, despite his heavy teaching load, he kept up work on the problem of intelligence. Together with a student, Kenneth Williams, he developed a variable-path rat maze as an analogue to human intelligence tests. The Hebb-Williams maze was widely used for the next quarter century. But Hebb was proudest of a theoretical paper in which he proposed that adult intelligence was crucially influenced by experience during infancy, basing his argument on the results of his research at the Montreal Neurological Institute. The paper was virtually ignored at the time, although it is now accepted almost as a commonplace, having been embodied in such preschool enrichment programs as Head Start. But the concept was too advanced for its time: in 1940 most psychologists practically defined intelligence as an innate characteristic.

To reconcile his studies of childhood influences with the apparent harmlessness of frontal-lobe lesions, Hebb hypothesized that the region's main function was not to think but rather to facilitate the tremendous acquisition of knowledge during the first few years of life. Experiments to determine the relative effects of early and late brain lesions did not always support this idea, but it provided a stepping-stone to Hebb's later theories.

In 1942 Lashley became the director of the Yerkes Laboratories of Primate Biology in Florida, and he invited Hebb to join his research team to study chimpanzee behavior. Hebb jumped at the chance of doing full-time research with




**HYPOTHETICAL CELL ASSEMBLY begins with parallel fibers connecting input from the retina to corresponding points in the primary visual cortex. These neurons, in turn, connect to the "association" cortex. Converging input fires cells and activates closed loops (*dark red*). Synaptic changes ensue that enable the loop to fire with little input, producing output that represents to the brain what the eye has seen.**




**RETINAL FATIGUE supports the cell-assembly theory by causing images to fade in a peculiar fashion. The apparatus fixes an image on receptors until their signal decays. Then lines drop out, one or two at a time, until the figure is gone. Hebb argued that each line was represented by a neuronal feedback loop. When the retinal signal falls below the critical value, the loop stops oscillating, and the line disappears.**

Lashley again, although he was not at first very enthusiastic about working with chimpanzees. Lashley's intention was to develop tests of learning and problem solving for the animals, while Hebb would study their personalities and emotional characteristics. Then they would start a program to determine how brain lesions affected a range of variables.

The chimpanzees proved more difficult to train than Lashley had imagined. The delays meant that no brain operations were carried out during Hebb's tenure at Yerkes. Nevertheless, he was fascinated by his observations of chimpanzees and said he learned more about human personality in his five years of watching chimpanzees than at any other time since his own first five years of life. The apes manifested distinct personalities and a sense of fun that tended toward slapstick. Hebb and the other members of the staff derived a more cerebral amusement from the verbal contortions of orthodox behaviorist visitors as they attempted to describe the animals' practical jokes and broad clowning without resorting to "mentalistic" language.

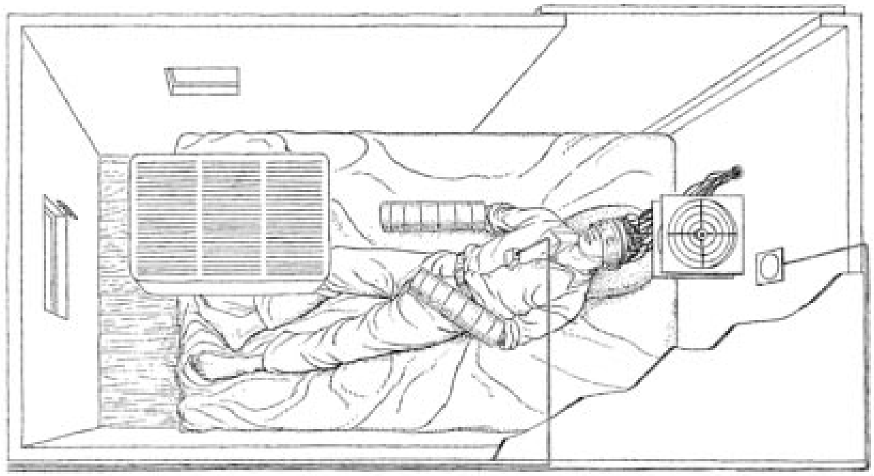
Hebb's long and close observation of the many chimpanzees in the primate laboratory taught him that experience was not the only factor in the development of personality, including pathological manifestations such as phobias. He showed, for example, that young chimpanzees, born in the laboratory and known never to have seen a snake before, are frightened the first time they are shown one. Chimpanzees are also frightened of models of chimpanzee or human heads or other isolated body parts or of familiar caretakers wearing unusual clothing. Moreover, Hebb was one of the first to observe the social behavior of captive porpoises and to suggest that it implied a level of intelligence comparable to that of the apes. His observations may have influenced his later conclusion that level of play provides a good index of intelligence.

Lashley's interest in the ways the brain categorizes perceptions into knowledge about the world rekindled Hebb's curiosity about concepts and thinking. The problem can be rephrased as a question: How does the brain learn to lump one triangle, car or dog with another even though no two triangles, cars or dogs produce the same pattern of stimulation on sensory receptors?

The turning point came when Hebb read about the work of Rafael Lorente de Nó, a neurophysiologist at the Rockefeller Institute for Medical Research, who had discovered neural loops, or feedback paths, in the brain. Up to that point, all psychological theories, whether physiological or not, assumed that information passed through the organism along a one-way track, like food through the digestive system. Hebb recognized that Lorente's looping paths were just what he needed to develop a more realistic theory of the mind.

Feedback was not entirely new in learning theory. Almost all models assumed that the output of the organism influences the input in some way, for instance, by enabling the animal to receive a reinforcing stimulus. Unfortunately, feedback proceeding in this way, through a single path, would operate slowly and often unreliably. But with millions of internally connected feedback paths, it would clearly be possible to establish internal models of the environment that might predict the effects of possible responses without having to move a muscle.

Hebb's specialization in vision led him to concentrate his early neural theories on that system. Knowing that the point-to-point projection from the retina to the cortex does not extend beyond the primary visual cortex, he assumed that the neural relays projected into the surrounding cortex in random directions, thus scrambling the retinal pattern [see "The Visual Image in Mind and Brain," by Semir Zeki; SCIENTIFIC AMERICAN, September 1992]. Such an arrangement could recombine signals from different parts of the image—that is, they could converge on the same target neuron, causing it to fire. The resulting impulses could then return to the earlier neurons in the path, closing the feedback loops.



**ISOLATION EXPERIMENT carried the study of sensory deprivation beyond the realm of individual cell assemblies. Cuffs prevented touch, a plastic shield disrupted pattern vision and a U-shaped foam cushion attenuated sounds not masked by the air conditioner in the ceiling. EEG electrodes recorded the subject's brain waves, and a microphone enabled him to report his experiences. The volunteers' ability to think deteriorated, and some of them even started to hallucinate.**

Repeated activation of any given loop might then strengthen that loop in the following way. If the axon of an "input" neuron is near enough to excite a target neuron, and if it persistently takes part in firing the target neuron, some growth process takes place in one or both cells to increase the efficiency of the input neuron's stimulation. Synapses that behave according to this postulate became known as Hebb synapses—somewhat to Hebb's amusement, it may be said, because this postulate is one of the few aspects of the theory he did not consider completely original. Something like it had been proposed by many psychologists, including Freud in his early years as a neurobiologist.

Nevertheless, Hebb's postulate was the most clear and formal statement, although in 1949 it was pure speculation. Since then, however, studies of single neurons have confirmed that synaptic strengths do change in some neurons in accordance with the postulate. Hebb may also have been correct about the mechanism of permanent change. A former student of his, Aryeh Routtenberg of Northwestern University, has recently pointed out that a protein associated with neuronal growth is produced when neurons are stimulated in ways that increase synaptic strength.

Hebb assumed that most of the synapses in the cortical lattice are initially too weak to fire spontaneously. To fire, they would require the converging of stimulation from a number of active neurons. Some neurons in the lattice receive converging inputs and thus fire when a particular pattern of neurons in the sensory cortex is fired by a stimulus. Some of the activated neurons have

**HEBB'S INFLUENCE propagated as much through his disciples as through his publications. Here, in a graduate seminar from the early 1950s, Hebb appears at the far right, the author in the foreground. The participants went on to pioneer the new field of physiological psychology.**

BEN DOAN *Dalhousie University* — HELEN MAHUT *Northeastern University* — PETER MILNER *McGill University* — JIM OLDS *Caltech* (DECEASED)

synaptic connections with one another, which are also strengthened whenever the stimulus is presented. Eventually the connections between the simultaneously firing neurons in the lattice become strong enough for them to continue firing one another in the absence of input from the stimulus, creating an internal representation of the stimulus, called a "cell assembly" by Hebb.

The concept of the cell assembly, in my view, was Hebb's greatest contribution to psychological theory, not to mention philosophy. It revived the 19th-century psychologists' attempt to explain behavior in terms of the association of ideas, a project that the behaviorists had derailed by arguing that "ideas" were no more real than the notion of little men inside the head. By so arguing, the behaviorists maintained that ideas, and thus mentalism, had no place in scientific psychology.

Unfortunately, few seemed to notice that the behaviorists replaced ideas with equally insubstantial constructs with misleading names, such as "stimuli" and "responses." These were not real events or chains of events but attributes that became associated with one another in some imaginary black box that scientists were forbidden to refer to as the brain. Hebb put a stop to this charade by showing, in principle at least, that ideas could have just as firm a physical basis as muscle movements. They could consist of learned patterns of neuronal firing in the brain, initially driven by sensory input but eventually acquiring autonomous status.

In its original form the neural theory was undoubtedly too simple to have worked. A major problem was that the cell assembly did not incorporate inhibition, because contemporary science did not recognize it. Sir John C. Eccles, a very influential neurophysiologist at the Australian National University in Canberra, was still vigorously denying the existence of inhibitory synapses. Moreover, many important connections of the neocortex had not yet been discovered, and the functional significance of the diversity of cortical neurons was only hinted at.

Without inhibiting factors, however, learning would strengthen synaptic connections until all neurons fired continuously, making the system useless. This effect was observed in computer models of the cell assembly, called conceptors, constructed in the 1950s by Nathaniel Rochester and his colleagues at the IBM research laboratory in Poughkeepsie, N.Y. Hebb himself seems never to have set finger to a computer to test his idea that random nerve nets could organize themselves to store and retrieve information. But such so-called neural nets later inspired many computer models, from the perceptron to parallel distributed processing, and have even found applications in industry.

By the time *The Organization of Behavior* reached publication, Hebb was back in Montreal as chairman of McGill's psychology department. Ten years later, when he stepped down as chairman, he had forged one of the strongest departments in North America. He found it easier to build what he wanted because the department was almost nonexistent when he began, and he turned out to be adept at campus politics and soon discovered how to use his growing reputation to apply pressure where it would do the most good. It is perhaps significant that he was also one of the best chess players at the university.

Most of Hebb's research at McGill was related to his cell-assembly theory. Experiments to obtain direct physiological evidence for the theory were far beyond the scope of contemporary methodology. (They still are.) Instead he tested behavioral predictions of the theory. He tried, for instance, to strengthen his earlier conclusions on the influence of rearing on adult intelligence. Most of the results supported his theory that animals raised in an enriched, or more complex, environment would, in later life, outperform animals raised in bare cages.

There was one embarrassing exception. Litters of pure-bred Scotties were split, and half the pups were reared as pets in the homes of members of the staff and half were reared in cages in the laboratory. Hebb was not fortunate in the choice of his puppy, Henry. It was congenitally incapable of finding its way around, invariably got lost as soon as it was out of sight of the house and had to be recovered from the dog pound on several occasions. Naturally, Henry turned out to be near the bottom of the class when, as a full-grown dog, it was tested in a maze.

In a related series of experiments, Hebb investigated the effect of impoverished sensory input on the behavior of adults, including human volunteers [see "The Pathology of Boredom," by

G. ROLFE MORRISON *McMaster University* — UNIDENTIFIED — SETH SHARPLESS *University of Colorado, Boulder* — DONALD O. HEBB *McGill University* (DECEASED)

Woodburn Heron; SCIENTIFIC AMERICAN, January 1957]. Students were paid generously to undergo severe sensory deprivation for as long as they could stand it (none lasted even a week). Their ability to think began to deteriorate, and some of them even started to hallucinate. The Korean War was then in progress, and many workers attempted to use such isolation experiments to understand and combat the "brainwashing" techniques employed by the Chinese.

Hebb also pursued his old idea that early brain injury should be more damaging than injury in an adult. But the results were rendered uncertain by several factors, the most important being the capacity of the young brain to reorganize itself. For example, if an infant sustains an injury in an area of the left hemisphere that is important for speech in the adult, the right hemisphere takes over this function, and speech is not seriously impaired. But if an adult sustains damage in the same area, the result may be a permanent loss of language skills.

Because of such problems with the study of cognition, Hebb came to believe that the best evidence for the cell assembly came from experiments on retinal fading. Images of simple figures were projected onto the eye by a very small lens system attached to a contact lens, ensuring that the image always fell on the same place. As the receptor cells become fatigued, the image fades and disappears, but not all at once. Usually entire lines disappear suddenly, one or two at a time, until the entire figure is gone. Hebb explained the phenomenon by saying that each line is represented by neuronal activity circulating in a closed loop. The activity, once started, continues even after the input from the retina has decayed to a low value because of feedback around the loop. But at some critical value the reverberation stops abruptly, and the line disappears. These experiments do not provide conclusive evidence for the cell assembly as Hebb envisaged it. Yet even if Hebb's version should turn out to be incorrect, it would not diminish the value of his idea that some neural activity continues to symbolize an object even after the object has stopped stimulating the sense organs.

Had *The Organization of Behavior* consisted only of the chapters in which Hebb criticizes current approaches and elaborates his cell-assembly theory, it is likely that few people would have read it. The book's appeal lies in its second half, in which Hebb discusses emotion, motivation, mental illness and the intelligence of humans and other species in the light of his theory. These essays are refreshingly forthright. On mental health, for example, Hebb wrote: "We still need an Ajax to stand up and defy the lightning and ask, What is the evidence? when some authority informs the public that believing in Santa Claus is bad for children, that comic books lead to psychological degeneracy, that asthma is due to a hidden mental illness."

Hebb built his department and his field by capturing the interest and imagination of the best students at an early stage. He taught the introductory course himself, making it immensely popular—at one point it numbered 1,500 students, about half the yearly undergraduate enrollment. Many future professors of psychology found their calling in these lectures. Like most of what Hebb did, his course was unique; no textbook at the time came close to including the material and ideas he dealt with, so he wrote his own. The first edition of *A Textbook of Psychology* appeared in 1958. In contrast to the majority of introductory texts of the day, it had more ideas than pictures.

Hebb also gave a graduate seminar that was attended by every psychology graduate student at McGill over a period of 30 years. It was famous not only for its stimulating discourse but also for Hebb's ever-present stopwatch and the slips of paper on which he noted incorrect pronunciations and other errors of presentation. It was Hebb's ambition never to have a McGill student overrun his or her allotted time at a meeting, and on the whole he was successful. McGill honored Hebb in 1970 by naming him chancellor; he became the only faculty member ever appointed to that position.

In 1977 Hebb retired to his birthplace in Nova Scotia, where he completed his last book, *Essay on Mind.* He was appointed an honorary professor of psychology at his alma mater, Dalhousie, and regularly participated in colloquia there until his death, at 81, in 1985.

FURTHER READING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