THE LAWS OF LEARNING¹

BY M. E. HAGGERTY

Indiana University

Modifiability of behavior has now been demonstrated in a large number of animals, ranging from the single-celled stentor and paramæcium up to the complex mammals and man. Two inferences lie near at hand: First, that modifiability of behavior is a general characteristic of animal protoplasm. Second, that the several processes which in various animals are called learning, habit-formation, memory, association, etc., are at bottom one and the same process and explainable by the same laws. As the phenomenon is demonstrated in one after another animal it becomes increasingly important to determine the primary laws upon which learning depends. It is the purpose of this paper to analyze certain factors involved in the simplest case of learning, to advance an hypothesis regarding the fundamental laws of all learning, and to show the value of this hypothesis in the explanation of different forms of learning.

One of the simplest cases of learning is to be found in the stentor described by Jennings. This behavior occurs when a large quantity of carmine grains are sifted into the water currents which the stentor draws toward its disk.

"Under these circumstances," says Jennings, "the normal movements are at first not changed. The particles of carmine are taken into the pouch and into the mouth, whence they pass into the internal protoplasm. If the cloud of particles is very dense or if it is accompanied by a slight chemical stimulus, as is usually the case with carmine grains, this behavior lasts but a short time; then a definite reaction supervenes. The animal bends to one side—always in the case of the stentor to the aboral side. It thus as a rule avoids the cloud of particles unless the latter is very large. This simple method turns out to be more effective in getting rid of stimuli of all sorts than might have been expected. If the first reaction is not successful, it is repeated one or more times. This reaction corresponds closely with the 'avoiding reaction' of free-swimming infusoria, and like the latter, is usually accompanied by revolution on its long axis,—the animal twisting on its stalk two or three times as it bends toward the aboral side.

¹ A first draft of this paper was read at the meeting of the Western Branch of the American Psychological Association, University of Chicago, April 5, 1912, under the title 'Transferred Associations.'

"If the repeated turning toward one side does not relieve the animal, so that the particles of carmine continue to come in a dense cloud, another reaction is tried. The ciliary movement is suddenly reversed in direction so that the particles against the disk and in the pouch are thrown off. The water current is driven away from the disk instead of toward it. This lasts but an instant, then the current is continued in the usual way. If the particles continue to come, the reversal is repeated two or three times in rapid succession. . . .

"If the stentor does not get rid of the stimulation in either of the ways just described, it contracts into its tube. In this way it, of course, escapes the stimulation completely, but at the expense of suspending its activity and losing all opportunity for food. The animal usually remains in the tube about half a minute, then extends. When its body has reached about two thirds its original length, the ciliary disk begins to unfold and the cilia to act, causing currents of water to reach the disk, as before.

"We have now," continues the author, "reached a specially interesting point in the experiment. Suppose that the water currents again bring the carmine grains. The stimulus and all the surroundings remain the same as they were at the beginning. Will the stentor behave as it did at the beginning? Will it at first not react, then bend to one side, then reverse the current, then contract, passing anew through the whole series of reactions? Or shall we find that it has become changed by the experiences it has passed through, so that it will now contract again into its tube as soon as stimulated?

"We find the latter to be the case. As soon as the carmine grains reach its disk, it at once contracts again. This may be repeated many times, as often as the particles come to the disk, for ten or fifteen minutes. Now the animal after each contraction stays a little longer in the tube than it did at first. Finally it ceases to extend, but contracts repeatedly and violently while still enclosed in its tube. In this way the attachment of its foot to the object is broken away and the animal is free. Now it leaves its tube and swims away."

I take this bit of behavior for what the experimenter interprets it to be, namely, a case of modification through experience, a case of learning, though one must admit that it is probably an easily forgotten bit of education. In trying to derive from it the primary laws of learning I shall first present Jennings' own explanation. That author's fundamental formula for the behavior of organisms is this: the external stimulus plus the present physiological state of the organism equals the reaction. In the behavior of the stentor just described the external stimulus remains the same; the behavior of the animal changes; therefore the stentor must have undergone a change in its physiological state. Symbolizing the physiological states accompanying the changes in reaction by capital letters we have in succession states *A*, *B*, *C*, and *D*. Jennings writes:

"The course of the changes in physiological states may then be represented as follows:

$$A \rightarrow B \rightarrow C \rightarrow D$$

Now we find that after many repetitions of the stimulation the organism contracts at once as soon as the carmine comes in contact with it. In other words, the first condition *A* passes at once to the condition *D* and this results in immediate contraction.

$$A \rightarrow D$$

It seems probable that the same series occurs as before, save that conditions *B* and *C* are now passed rapidly and in a modified way, so that they do not result in a reaction: but are resolved directly into *D*. The process would then be represented as follows:

$$A \rightarrow B' \rightarrow C' \rightarrow D$$

But whatever the intermediate conditions, it is clear that after state *A* has been resolved through pressure of external conditions into state *D* this resolution takes place more readily, occurring at once after the state *A* is reached."

In the last paragraph Jennings makes a gratuitous assumption which is probably not correct. He suggests that states *B* and *C* persist but in a 'modified way.' This is gratuitous, because there is no evidence that they do persist and from what we know about learning in other cases we are justified in inferring that they do not persist. In learning any bodily act what one experiences is the elimination of useless intermediary movements. If on his first attempt one makes a series of movements which may be designated as 1, 2, 3, 4, 5, 6, 7, 8, 9, he may on the second attempt drop out movement 3 and in succeeding practices lose all but Nos. 1, 6 and 9. When he has once acquired the 1-6-9 habit the intermediate steps have been suppressed and eliminated from the series. He does not experience acts 2, 3, 4, 5, 7, 8 as 'passing in rapid succession.' They simply are not there at all when the habit has once been perfected. In fact after the formation of many habits the injection of the intermediate steps becomes an impossibility. If one has difficulty in believing this let him try to walk, or write, or swing indian clubs or ride a bicycle, or do any other complicated act in exactly the manner in which he at first did it. All of us at one time talked in the halting child fashion. Not one in a thousand of us can do it now and it is only the exceptionally skillful professional reader who can create either for himself or others the illusion of child speech. Yet at one time it was the natural manner of every person. If these intermediate steps still persist but pass more rapidly and in a modified way why is it not possible merely by slowing down the process to reinstate each of these rapidly passing

states in the original series? What we all know is that slowing down the process does us no good whatever. The reasonable inference is then that the 'useless' intermediate states have been wholly eliminated. They have been suppressed and permanently inhibited, short circuited by virtue of originally distant states becoming fused together.

In interpreting the modification of the stentor's acts then it is fully as consonant with the observed facts of behavior in the stentor and far more in harmony with the facts of human learning to say that, in the modified behavior of the animal, states *B* and *C* have been wholly eliminated. They are no longer 'passed rapidly and in a modified way.' They are simply not there at all. Instead of having

$$A \rightarrow B' \rightarrow C' \rightarrow D$$

we have

$$A \rightarrow D.$$

It is probably true as Jennings states his law of learning that "the resolution of one physiological state into another becomes easier and more rapid after it has taken place a number of times," but such a law will not account for the fact that at one time a physiological state *A* will 'be resolved' into another physiological state *B* and at another time the same state *A* will be resolved into state *D*. In order to account for this shift of 'resolution' another law has been proposed called the law of effect. This law says that there is something about the state *D* which determines that *A* shall be 'resolved' into state *D* instead of into state *B*. *D* has a reversionary influence and determines the course which the state *A* shall take on its next appearance.

Now there can be no doubt that the 'law of effect' furnishes a much needed supplementation to the 'law of exercise,' or the law of the 'readier resolution of physiological states after practice.' There is simply an unlimited number of cases, many of them experimentally determined, which demand both of these laws. However, when one tries to conceive what the law of effect can mean in detail and especially what it can mean in such a simple organism as the stentor or paramæcium

he strikes a number of very puzzling problems. One of these has already received consideration at the hands of numerous writers. This is the problem of the nature of the effect; and it must be admitted that the discussion has not as yet led to any very illuminating results. The recent discussions which have held positively to this theory have been content with merely affirming that 'effect' exists and leaves to further investigation the problem of determining the nature of the effect in question. It is the further purpose of this paper to examine some of the conditions under which 'effect' can operate. It makes no pretense of giving a complete analysis.

When one tries to conceive a series of physiological states there generally comes to mind a series of physical objects. One may think of a series of cars, a series of waves in the water, a series of sounds or a series of movements of an animal such as the successive steps in walking. In each of these cases the series is made up of two or more units more or less closely juxtaposed. Taking the series in which the separation is least distinct, namely the waves of water, you yet are able to distinguish a region within which you can say that one wave ends and the second begins. It is clear that the crest of one wave is gone from a certain point before the arrival of the second crest, and further, there is no conceivable connection between wave one and a third or fourth wave except through the intermediate waves. Now if one carries this conception over to the case of learning and applies it to the case of the stentor then he must understand that state *A* is directly connected with state *B* and through *B* with *C* and so on. There is no connection between state *A* and state *D*. But upon this hypothesis there is no conceivable way in which state *D* could become connected with state *A* in such a manner as to eliminate *B* and *C*. One must conceive that state *A* in some manner persists until state *D* comes into existence. It is only when the two states coexist that the law of effect can work. When they do coexist we can imagine that there is some condition about *D* which ties it to *A* rather than to any other state. But in order that we may have the coexistence we must have a condition in which a physiological state overlaps and reaches

beyond its immediately neighboring state. This condition I have chosen to call the *condition of irradiation* and to name a law which may be called the *law of irradiation*. Stated simply this law is that *a physiological state is not self contained but it tends to flow over and mingle with other physiological states and extends to states temporally removed from it.*

That two or more physiological states may coexist in a single celled animal is shown by the behavior of paramæcium under two or more stimuli. "If the animal is at rest against a mass of vegetable matter, or a bit of paper under the action of the contact stimulus, and is then struck with the tip of a glass rod, we find that at first it may not react to the latter stimulus at all. A touch that would cause the free swimming specimen to give the avoiding reaction in a pronounced way often has no effect on the quiet specimen. Sometimes, however, a touch coming from behind causes the animal to move forward, still remaining in contact with the solid object; it thus creeps a short distance over the surface of the solid. . . . Thus we find that under the simultaneous action of the two stimuli the infusorian may either react to the more effective of the two, whichever it is, without regard to the other, or its behavior may be a sort of compromise between the usual results of both." In such a case as this you have clear evidence that a single cell may be the bearer of two or more physiological states at the same time and that both may be effective at the same time in determining the animal's behavior. This fact gives us additional reason to believe that the appearance of a physiological state *B* in the series does not thrust out of the organism all other states and gives ground for believing that state *A* may still continue across several intervening states.

The facts thus evident in protozoa have their counterpart in the results of experiments on remote and retroactive memory in human beings. In these experiments a series of nonsense syllables is learned by the Ebbinghaus method. It is found then that if the series is turned about and learned in the reverse order there is a distinct saving in time in the second learning. Similarly it is found that if each alternate syllable is omitted and the remaining syllables are learned in the direct

order there is again a distinct saving over learning the same number of syllables without the previous learning. It is thus indicated that the associative ties formed in the first learning are formed not only between the successive members of the series but that associative connections are also made between the alternate members, and further that connections are made in the reverse direction from the original learning.

It is difficult to speak of the radiation of a physiological state without thinking of it in purely spatial terms. Yet in the case of the single celled animals there is no ground for assuming spatial factors. There are no organs spatially arranged which could mediate the facts observed. What we have sufficient ground for inferring is the changes in physiological states. The nature of the change we must refer to physiological chemistry if it is to have a scientific explanation at all. Just for this reason I would distinguish the radiation of a physiological state from the concept of diffusion applied to the nervous conditions in the complex nervous systems. The latter is always conceived in spatial terms and when one thinks of a nervous impulse diffusing through the nervous system he thinks of a fluid running through tubes or some other mechanical contrivance. It is just this conception which is not applicable to the cases in lower organisms and it may be due to this mechanical conception that we remain in such gloom about the relation of the brain to higher animal activities.

Such a theory as I have outlined has important bearing upon the psychological and neurological problems in the psychology of learning. Let us consider the neurological problem first. All our attempts to know what goes on in the brain during a learning process are founded upon a mechanical conception of the nervous system. We talk of cord and cortex, of neural levels and localization, of cells and fibers, of neurones and synapses. *Our problem is always to conceive how such a mechanical system can so operate that variable behavior is possible.* The latest attempt to provide an intelligible theory is to be found in the literature of the synapse. It is in the membranes between the fine tendril endings of the neurones we are told that there exists the condition for variability of behavior.

These membranes offer resistance to the passage of the nervous current and here something must occur which is different from the ordinary passage of the nerve impulse through a neurone. In one case the resistance may be overcome in one direction but at another time it is broken down in an entirely diverse direction. The cortical neurones are supposedly primitive cells and yet retain some of their original protoplasmic properties among which is the power of amoeboid movement. A stimulated neurone stretches out one of its processes in one direction and touches or comes near the processes of a neighboring neurone and there is thus formed a physiologically continuous circuit. When once the impulse has run its course the amoeboid process recoils. At another time a different process may be thrust out touching a different cell and thus provide on the occurrence of the second stimulation an entirely different form of reaction. *What is still lacking to make this theory satisfactory is some explanation why at one time the one amoeboid movement occurs and at another time another takes place.* As yet there has been no sufficient solution of this problem.

In the presence of the failure of the synapse theory to give us a sufficient explanation of learning and modifiable behavior it may be proper to inquire if we are not expecting too much from the purely mechanical nature of the nervous system. Possibly the condition within a single cortical neurone itself is more complex than we have been assuming it to be. If we allow ourselves to think of the cerebral neurone as retaining the characteristics of primitive animal protoplasm may it not be true that it retains the property found in the stentor and paramaecium of being the bearer of several physiological states at one and the same time. This is no more a speculation than it is to suppose that it still has the power of amoeboid movement. There is reason to think that it may be a much more fruitful hypothesis. *Under this hypothesis the problem of learning becomes the problem of understanding the nature of intra-neuronic activity rather than that of inter-neuronic relations.* The crux of the learning problem shifts to a consideration of the origin and relation of the several physiological states occur-

ring simultaneously within single neurones rather than to a study of membranes and anatomically distinct elements. Structural neurology is, to a large extent, relieved of a task which it has not been able to meet and we are thrown back upon physiological chemistry and the study of animal behavior for our explanation.

It is in this last fact that the hopefulness of this theory inheres. If the behavior student of the lower organisms can give us an experimental analysis of all the factors involved in the learning of the stentor and paramæcium he may take us a long way toward explaining the neurological problem in human learning. Because the materials are so readily accessible there is some hope that he may do so.

The complete analysis of learning in any animal should greatly clarify our perception of the essential factors in all learning. Much of the discussion of this topic assumes that we have three sharply divided kinds of learning processes, namely, learning by trial and accidental success, learning by imitation, and learning by deliberation, by thought, or by reason. Whether or not these three forms of learning occur in either animals or man is a question to be determined by observation and experiment. But in attempting to experiment in this field the investigator confronts the difficulty of being unable to observe the learning process in detail. In the case of animals he is confined to such observations as he can make on the overt behavior of the animal and in the case of man he can only supplement this sort of evidence with introspective accounts of the learning process as it appears to consciousness. As a result there is always the possibility that the facts open to common observation may be but the outward expression of more recondite processes which can be only indirectly inferred. If we could only make a detailed and final observation on these hidden processes we might discover that they are common to all of the customary groups of learning. It may be that these several forms of learning are like the lines diverging from a single point. If one looks at them at some remove from their origin they seem far apart, but if they are traced back to their beginning it is found that they come from a common source.

Imitation as a finished product may seem very unlike trial and accidental success and the latter may seem much more unlike learning by deliberation, but if we could only get at the details of these processes they might be found to be very much alike and to be but variations of a common neural activity. Traced back to their common ground it might be found that learning by trial and accidental success, learning by imitation and learning by deliberation or by free ideas are all essentially like the learning of the stentor and that each of these forms of learning involves the law of exercise, the law of effect and the law of irradiation of physiological states together with whatever other laws the experimental analysis of animal behavior may bring to light.

In suggesting the discovery of yet other laws it is not intended that these new laws will invalidate the laws already worked out. Further progress would rather seem to lie in the direction of the elucidation and amplification of these fundamental laws already discovered.

In order to make clear what is meant by tracing the higher forms of learning back to the simpler forms let me illustrate by the case of imitation. A group of children were playing together on the floor. Suddenly one of the older children grabbed a cap from the chair and placing it on the end of her finger waved it about in the air above her head. A small boy three years old picked up another cap and placing it on the end of his finger waved it above his head. A naïve observer would have called this a case of imitation and for purposes of description there is probably no better way to designate the act in question. That the act was new to the second child was evident from the irregular manner of his movements and this was confirmed by the testimony of the parents who had observed the boy's development with critical interest. It was probably true that the particular combination of movements involved in the act was essentially a new experience for him. The stimulus for the new act was the behavior of the other child; the result was behavior much like the behavior of the child seen. This combination of circumstances, an act in one person serving as a stimulus to produce in another person behavior

resembling the behavior of the first person, constitutes the phenomena called imitation. Let us see now to what extent this imitative behavior can be explained by the elemental laws of learning stated above.

First it is to be noted that the imitative act is not wholly new. The child already has the habit of lifting his arm, clenching his fist, pointing his index finger, etc. There are also present the habits of observation, of seeing, etc., involved in perceiving what the other child does. It will simplify our explanation somewhat if we designate these two sets of activities by letters. Let the set of perceptive processes be designated by the letters, *a, b, c, d, e, f*, and *g* and let the muscular movements be represented by the letters *h, i, j, k, l, m*, and *n*. Now it is perfectly conceivable that these two habit chains might exist simultaneously in the nervous system and yet have no relation with each other that would be expressed in outward behavior. In such a case the observation of the playmate would never cause the child to go through the series of acts witnessed. There would be no imitation. That there are coexisting such unassociated habit chains in every nervous system there can be no doubt. But on the other hand suppose that the physiological state represented by *g* exists in close proximity to the physiological state *h* of the other habit chain and suppose that there was radiation laterally as well as in the direction of the temporal sequence, it is possible that something might cause state *g* to become coalescent with state *h* and all the rest would follow as a matter of habit. The only thing necessary to bring about imitation would be the possibility of radiation in a direction other than that of temporal sequence. In the formation of a habit a physiological state must overlap to the succeeding state of the series. In the case of imitative learning the overlapping must be to states not in the temporal series. If this possibility is granted all that is further needed is some variable that will for the first time cause this overlapping to be sufficient. This variable may be found in the states accompanying excitement, emotion, clearness of perception, etc.

The advantage of such a conception of learning as this is

that one can hold to a physico-chemical theory of animal behavior and yet not deny the existence of such activities as imitative learning, learning by free ideas, transfer of training, etc. Or to put it the other way he can recognize the existence of these latter processes and yet not have to invoke supernatural entities in order to explain them. They are all finally reducible to the same basic processes.

Take the case of what are called free ideas. A free idea is not an unrelated idea. It is merely a physiological state that is not rigidly bound within a single linear series of physiological states. Its lateral overlappings are as numerous and as potent as the linear ones, and they are not overcome and inhibited by virtue of its once being caught up in a particular chain of experiences. From this point of view the so-called free idea appears as of the same stuff as the simple physiological state of a stentor and a paramæcium. Between the condition of the infusorian and that of man there are many intermediate levels of physiological states, but all of them are of essentially the same sort of protoplasmic function.

In the light of all these matters the law of radiation may be stated as follows: A physiological state is not self-contained but tends to radiate to other physiological states both those which form with it a series of states like a habit chain and also to other physiological states which have never formed a series with it.

By virtue of this linear radiation the formation of single habit chains can be explained. By virtue of the lateral radiation can be explained all the higher forms of learning including imitation and learning by the use of free ideas. By virtue of the law as a whole all learning is reduced to physical terms and there is no longer need to invoke ghosts in the form of consciousness to explain the higher forms of mental activities.