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NEUROLOGICAL NOTES ON THE ART OF EDUCATION

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CHAPTER IV

Neurological Notes on the Art of Educating

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We know an object when we know how it is made, and we know how it is made in the degree in which we ourselves make it. Old tradition compels us to call thinking "mental." But "mental" thought is but partial experimentation, terminating in preliminary readjustments, confined within the organism. As long as thinking remained at this stage, it protected itself by regarding this introverted truncation as evidence of an immaterial reason superior to and independent of body. As long as thought was thus cooped up, overt action in the "outer" natural scene was inevitably shorn of its full meed of meaning; it was to that extent arbitrary and routine. *When "outer" and "inner" activity came together in a single experimental operation,* used as the only adequate method of discovery and proof, effective criticism, *consistent and ordered valuation, emerged. Thought aligned itself with other arts that shape objects by informing things with meaning* [Italics mine].[1]

When asked to contribute to this yearbook I was delighted—problems of education are my daily fare, and I have developed some prides and some prejudices on how one goes about learning and teaching. Second consideration, however, led to hesitancy—for I was to say something of physiological import to educators. What on earth could a neuropsychologist have to contribute? And third, a still more considerate question emerged—since when does the neurologist *not* have something to say in these matters? Was it really so very long ago (1913) that Thorndike[2] discussed the neurology of the capacity to learn and of readiness?

It has been a half century—a fruitful half century of functionalism and progressivism; of positivism and behaviorism; of Gestalt and

1. John Dewey, *Experience and Nature*, p. 346. LaSalle, Illinois: Open Court Publishing Co., 1958 (revised edition).

2. E. L. Thorndike, *Educational Psychology*. Vol. I, *The Original Nature of Man;* Vol. II, *The Psychology of Learning*. New York: Teachers College, Columbia University (Mason-Henry Press), 1913.

field; of conditioning and learning. Amazingly, Carmichael's 1940 yearbook chapter is the only one on the central nervous system in all these fifty years.[3]

Yet, neurological science has not been dormant in this interim. Why then the hiatus? Most likely because those working with cerebra produced little of relevance to those working with curricula. Meanwhile, those engaged in building a purely behavioral science did give answers to old questions.

So why *now* the nervous system? First, because recent results of neurochemical, neurophysiological, and neuropsychological experiments bear directly on problems of education. Second, because the answers given to these problems by the purely behavioral scientist have been so multiform and often conflicting and, yes I will say it, wrong—that education must be given some basis for choice among answers. A return to neuropsychological fundamentals can clarify issues and, on occasion, resolve them.

The issues are these. Behavioral science has, up to now, been overly concerned with externally placed guides on behavior. Lip service to organismic states has been rendered through reference to physiological needs, the so-called primary sources of satisfaction, of drive and reinforcement. This emphasis, in turn, did a misservice to education by placing external guides on the material to be taught. The view proposed here, a view derived from neurobehavioral research, is that the reinforcing process, basic to education, has an intrinsic organic, i.e., neurological, structure which respects the intrinsic structure of the materials to be taught. The job of education is to facilitate the matching of these two intrinsic structures, much as a sculptor matches his intrinsic vision to the intrinsic properties of stone. In this endeavor lies the art of educating.

On Readiness[4]

In the old scheme, knowledge, as science, signified precisely and exclusively turning away from change to the changeless. In the new experi-

3. Leonard Carmichael, "The Physiological Correlates of Intelligence," in *Intelligence: Its Nature and Nurture*, pp. 93–155. Thirty-ninth Yearbook of the National Society for the Study of Education, Part I. Chicago: Distributed by the University of Chicago Press, 1940.

4. Readiness is here used in the sense of immediate readiness to learn as implied in Thorndike's "law of readiness." It is related to, but not identical with, the readiness based on developmental level, as discussed in chap. ix (E.R.H.).

mental science, knowledge is obtained in exactly the opposite way, namely, through deliberate institution of a definite and specified course of change. *The* method of . . . inquiry is to introduce some change in order to see what other change ensues; the correlation between these changes . . . constitutes the definite and desired object of knowledge.[5]

The first question an educator must ask is how can an individual be readied to engage in the educational process? The question so stated is in many respects similar to that faced by the scientist who must devise an experiment to engage his subject matter. And the results of neurological investigations suggest that the nervous system also goes about the first steps of *its* task in much this same way.

When a person or animal is placed in a situation where the same tone is repeatedly "beeped" at irregular intervals, a sequence of events is observed. At first an orienting reaction can be recorded. Often the subject will turn head and eyes to locate the source of the sound. A galvanic skin response is recorded. Blood flow to the head is increased while that to the finger tips diminishes. Electrical activity of the parts of the brain connected to the internal ear show a choppy "activation" pattern characteristic of alerting. Other parts of the brain also give altered electrical records typically found when changes of state are taking place (e.g., theta rhythms are recorded from the hippocampal formation).

After about five to ten minutes in the repetitious environment, these behavioral and physiological indexes of orientation can no longer be observed. Habituation has occurred. The person (or animal) is apparently no longer reacting to the stimulus situation.

But this appearance is deceptive. Diminish the intensity of the tone slightly, and immediately the orienting reaction recurs. Or, after habituation is in full force, shorten the tone beep: orienting is again observed—but now to the "unexpected" silent period caused by the earlier termination of each beep. Obviously habituation reflects not a passive, "fatigued," inactivity of the organism, but, rather, a state of expectancy delicately tuned to recurrences in the situation. Any slight departure from prior conformations—any nuances—produce the orienting reaction.

The central nervous system is the repository of this state of ex-

5. John Dewey, *The Quest for Certainty*, p. 84. New York: Minton, Balch & Co., 1929.

pectancy. For instance, in the frog, nerve cells ("newness neurons") have been identified (in the optic tectum) which react with a burst of discharges whenever some novelty (such as a fly) is introduced into its visual field. These bursts rapidly diminish if the novel object remains in the field or after repeated presentations; other cells maintain an increased firing rate over longer periods "following" the presence of the object as long as it remains within the field.

Reaction to novelty thus appears to be one built-in feature of the central nervous system. The problem remains to identify the way in which neurons are organized so that the editing function of redundancy reduction, i.e., information enhancement, occurs. Repeatedly these aggregates of nerve cells must pose the question, "Is this news?" Already, some mechanisms are known. For instance, in the retina, contrast is enhanced by a process of "surround inhibition"—i.e., by a mechanism which shuts down on the activity of receptors that are neighbors of those directly excited. A similar mechanism has been shown operative in the cerebral cortex. Physiologists and psychologists of the Pavlovian persuasion refer to this process as external inhibition because it is induced by excitations derived from outside the organism. They contrast external with internal inhibition which builds up within the organism, especially during frustration. Internal inhibition is identified by its electrical concomitants and, in the extreme, is accompanied by behavioral sleep. Recently, Magoun has suggested that the various inhibitory mechanisms—all active neural processes—be thought of as arranged in a continuum. There is merit in this suggestion, though it poses some interesting problems.

Surround or external inhibition is observed to take place when microelectrode recordings are made from single strands of neurons. Neurons are known to have a spontaneous beat—i.e., they discharge rhythmically, much as does the heart, provided only that the tissue fluids in their surround remain physiological in their concentration of nutrients, respirants, and salts. When neurons are excited either by other neurons or by receptor events, their rate of "beating" or "firing" increases. As already noted, when this happens, records made from neighboring nerve cells show a diminution in the frequency of firing. And this is correlated behaviorally with an enhancement of the contrast between excited and nonexcited fields (e.g., vision). More of this in a moment.

Internal inhibition, on the other hand, is said to take place when gross electrical recordings from brain tissue show changes correlated with behavioral drowsiness or sleep. It is not known whether these gross electrical changes indicate an increase or decrease in the firing of individual nerve cells—techniques are not yet sufficiently far along to sample a large enough population of neurons at any one time to answer this question easily. Preliminary evidence indicates, however, that the activity recorded with gross electrodes is only partially correlated with the firing patterns obtained from neurons —that the gross electrodes record what are called changes in local graded responses of neural tissue, while microelectrodes record nerve impulses that are transmitted along the entire extent of the neuron. It is perfectly possible, though not yet established, that on certain occasions local, graded potentials of neural tissue increase, while the frequency of nerve impulse discharges of the same tissue decreases. The local graded response activity is recorded primarily from the dendrites of neurons and from the junctions between neurons (synapses) and between neurons and glia (gliapses). Nerve impulse transmission is, of course, largely a function of the axons of nerves. It is now well known that what happens in one part of the neuron does not necessarily reflect what is going on elsewhere in that same nerve cell.

To sum up, if neural inhibitory processes are, indeed, to be thought of in some unitary way, the suggestion must be seriously entertained that changes in the frequency of nerve impulses and changes in local graded neural potential can vary reciprocally. If this is so, the active neural process, which is called "inhibition" and observed to take place in the enhancement of contrast, could be expected to spread, i.e., involve more and more neighboring tissue. This organized, spreading, and gradually more-and-more-internalized inhibitory process would thus be called on to account for the phenomenon of habituation and, as already noted, is correlated with behavioral drowsiness and sleep. The suggested model does have appeal to those of us who have fought off this spread of "internal inhibition" while some speaker drones on and on and on. . . .

Return for a moment to the retina. There are other interesting phenomena. Place a mirror onto the sclera and arrange a slit of light so that it is reflected from the mirror onto a black background. Arrange also that the beam reflects accurately the angle of movement of the mirror. Now, whenever the eye moves, the arc described by the light on the black background is such that the identical retinal element is continuously excited. Within a half minute or a minute, the slit of light fades and disappears. Or put on sun glasses, and soon the relative brightness of objects will appear as before. These phenomena are traced to the rapid adaptation of retinal receptors. Each receptor element responds to change only briefly—then adaptation supervenes, and the frequency of firing returns to its prior basal rate. The reason we are able to see anything at all is that the eye is in continuous *movement*. Through movement, different receptors are momentarily brought into play with respect to an exciting stimulus. Thus, *movement provides an override on the process of adaptation so that perception can take place*. But adaptation, nonetheless, plays a role in making up, with surround inhibition, a mechanism for redundancy reduction. Convergence of the input from a group of receptors upon a single nerve cell in the central nervous system, a cell with the same property of adaptation, will result in a "newness neuron," sensitive only to "averages" of the changes in frequency of firing of the receptor pool from which it draws its input. And through surround inhibition among such centrally placed neurons, *this* "average" would be enhanced. A still more central neuron, drawing input from a population of these first-order neurons, again by simple convergence, would, by repeating the process again, reduce redundancy—i.e., react only to differences among differences.

But readiness is not all encompassed by the notion of newness. As already noted, movement provides an override on the mechanism of redundancy reduction. Try this experiment. Look at this book and move your eyes about it from corner to corner. The book and this page remain in place—they do not move, though your eye did. Now push your eyeball with a finger. Immediately the page goes shooting off in the direction opposite to the push you gave the eye. Somehow, active movement and passive movement of the eye give different results in perception. Many experiments involving different sensory modes have taken off from this simple observation, and it is now clear that active movement is accompanied by a presetting of the perceptual mechanism so that constancy of perception of the environment can be achieved. For our purposes here, what is important is that the override on the adaptation-habituation process is itself governed. If it were not, the world would go rushing by as an incomprehensible flux. This central control over active movement and, thus, perception is a story in itself—but, first, a few words about what these experimental results can say about the readiness of a person to become engaged in the educational process.

Neuropsychological experiment has demonstrated that an organism orients (attends) when, after exposure to recurrent events, these events *change. Novelty rises out of variations on the familiar.* And *everyone* must be familiar with something. The question is, how is the educator to ascertain what is familiar to his pupils. He cannot simply ask, for they will not be aware—they are habituated; by definition they cannot respond explicitly to that which is *most familiar.* The educator can, by knowing the background of his pupils, make heuristic probes—ask questions and give answers which, if they catch the attention of his pupils, will uncover the boundaries of the familiar. He may ask the students—once they become engaged, pupils have become students—to participate in the questions and especially the answers so that they may help in this uncovering of their own boundaries. In this way the students themselves immediately begin to exert some control on the override of the habituation mechanism—they move their "eyes" and do not have them moved from without. This is at least one safeguard that can be established so that the material presented does not go rushing by in an incomprehensible flux.

Once engaged, how is engagement maintained? Obviously repetitiousness carried to an extreme will lead to habituation and even to internal inhibition, drowsiness. But so will its opposite. If too many contrasting novelties are presented in too rapid succession, surround inhibition is, according to our model, apt to spread and become internal inhibition—the result, frustration and sleep. The good teacher, therefore, watches (much as an experimentalist watches for deflections of the indicators of *his* measuring instruments) these signs of alerting and dozing—the brightness of eyes, the expectant postures, and their converse—among students and paces himself accordingly.

There need be no guesswork involved in ascertaining "readiness." The neuropsychological laboratory has not only given first glimpses of the mechanisms involved—sufficient to demonstrate their importance as preparation for a learning experience. In addition, this work has also indicated the method that can be applied in evaluating readiness, viz., the observation of orienting reactions. That such application is feasible has already been demonstrated: an important technique regularly used in psychotherapy to "uncover unconscious processes" relies exactly on this procedure. The therapist notes and, in graded doses, points out to the patient excessive strengths (or lacks) of response that ordinarily would not be expected were the patient fully aware of what is the familiar to him—i.e., his "unconscious." As an educator, the teacher out of necessity watches the orienting reactions of his students. He might also fruitfully watch his own reactions during teaching as a means of self education. He does this by exploring in the same fashion his own familiarities, the nonexplicit assumptions with which he approaches his subject matter and which, on occasion, are brought "uncomfortably" to light by the "naïve" queries of his students. Thus, he himself becomes engaged in education—this turn, the pupils teach; the teacher learns.

The Capacity To Learn and To Remember

> There is little scientific writing which does not introduce at some point or other the idea of tendency. The idea of tendency unites in itself exclusion of prior design and inclusion of movement in a particular direction, a direction that may be either furthered or counteracted and frustrated, but which is intrinsic. Direction involves a limiting position, a point or goal of culminating stoppage, as well as an initial starting point. . . . [But this goal may be] an end-in-view and is [a] constant and cumulative re-enactment at each stage of forward movement. It is no longer a terminal point, external to the conditions that have led up to it; it is the continually developing meaning of present tendencies—the very things which as directed we call "means." The process is art and its product, no matter at what stage it be taken, is a work of art.[6]

Capacity calls to mind a fixity, a basic moiety of equipment which is subject to measurement, as by tests of intelligence. Yet, in his chapter on the anatomy and physiology of original tendencies,

6. Dewey, *Experience and Nature*, *op. cit.*, p. 302.

Thorndike discusses the changes presumed to occur at the synapse which might account for the capability to learn. If some such process is indeed involved in learning, capacity to learn could as well involve some changeable, changing baseline that needs recurrent reassessment to be meaningful. What is the evidence?

Great strides have recently been made in taking questions of memory storage into the laboratory. For over a century neurohistologists have asked whether neural growth can take place in the central nervous system after the initial period of development. Only within the last few years has an affirmative answer been obtained.

Rabbits were irradiated in a cyclotron so that one layer of the brain cortex was selectively damaged. This could be accomplished because the radiation is rapidly absorbed in soft tissue and so gives off its energy in a remarkably restricted range. Thus, a cell layer could be "excised" without damage to more superficial or to deeper layers. The studies were undertaken to determine some precise relations in the connections between deep-lying brain structures and the cortex. The investigators were, therefore, astounded to find that, after an initial period when destruction was evident, neural new growth had occurred in the area of the lesion. Nerve cells do not divide in the mature brain—nor did they in these rabbit preparations. What did happen was an orderly growth of fibers, probably branches from undamaged nerve fibers.

Of course, students are not rabbits, nor have they been exposed to the cyclotron's fury. But there is more. Another group of investigators, in following certain chemical changes produced in rat brains by differential amounts and kinds of experience, found that their results were correlated with changes in the thickness of the brain cortex involved. Rats given visual experience showed a differential thickening of the visual cortex; in blinded rats the differential thickening favored the somesthetic areas of the brain. Again the increase in tissue is not attributable to an increase in the number of nerve cells—the assumption must be that the increase is due to increased branching of the nerve-fiber network and an increase in the nonneural (e.g., glial) elements (which do continue to reproduce throughout life).

There is much more. Biochemists have shown that nerve cells secrete a greater abundance of ribonucleic acid than any other cells in the body. And ribonucleic acid, RNA, is a sister substance to DNA, the material from which genetic memory is fashioned. Glia are also involved in a longer-term process, which might reflect the fact that experienced events must go through a period of consolidation before they are memorized.

Some further distinctions are becoming clear. The mechanisms in the brain that serve learning and those that serve retention have been separately involved: lesions of the brain cortex (made with aluminum hydroxide cream), which cause marked disturbance of the electrical record, *impede learning* some five-fold but *leave intact retention* of solutions to problems. Conversely, removals of that same cortical tissue have little effect on the acquisition of new but related problem-solutions during any one training session; however, recall of the previous day's performances is severely restricted.

All this and more—but I have reviewed this material elsewhere in detail and there presented a model to suggest how the memory mechanism might be viewed.[7] Here it is sufficient to point out that inroads are being made—and they are of considerable proportion—on the age-old problem of organic changes occurring as a function of experience. The locus of that change is in the brain, and more specifically in the ramifications of finely branching nerve fibers and their relations with each other and with the glia in which they are embedded.

Thus educators, aware of these facts, can take seriously the experiments which show that an excessive "massing" of experiences leads to poor acquisition. Consolidation of the memory trace appears to be a two-fold process. The first part takes, at the most, an hour. During this hour the neural (probably neurochemical) traces set up by the experience are fragile. Not only will a blow on the head completely wipe them out—and cause a retrograde amnesia for immediately prior events—but in addition, these early traces are subject to "inhibition" through retroactive influences upon them by exposure to new and related material. The rate with which different persons consolidate their memory appears to differ. In one study some retarded children were found to perform as well as controls when their exposure to test trials in a problem was spaced sufficient-

7. Rather than cite the research studies in the body of the chapter, references can be found in the bibliography at the end.

ly far apart. In general, the old adage that "in a lecture few souls are saved after the first fifteen minutes" can be used as a rule of thumb—very few experiences per hour can be consolidated as far as we now know the physiological and behavioral evidence.

At this point the reader may well be saying to himself "My, but this fellow sounds old fashioned. Hasn't he heard of the marvels of teaching machines, or programed texts, of the process of reinforcement by which behavior is so gradually 'shaped' that in painless fashion mountains of facts can be acquired?" Yes, your author has heard of these methods and was privileged to be on the same program when Skinner initially reported these innovations. They are, indeed, powerful tools. What has neurobehavioral science to say about them?

The proper use of teaching machines and programed texts hinges on the more basic question of the nature of what constitutes reinforcement for an organism. And about reinforcement neuropsychologists have found out a great deal.

Teaching machines are direct descendants of Thorndike's second and third laws (the first was the Law of Readiness). The second is the Law of Exercise or Use, which states that "when a modifiable connection is made between a situation and a response, that connection's strength is, other things being equal, increased. By the strength of a connection is meant roughly the probability that the connection will be made when the situation recurs." The third law is, of course, the most famous—the Law of Effect: "When a modifiable connection between a situation and a response is made and is accompanied or followed by a satisfying state of affairs, that connection's strength is increased." The converse of these two laws in terms of "disuse" and an "annoying state of affairs" was also given. And psychologists have been busy since, in an attempt to give experimentally based substance to these laws.

The issues are: (*a*) what is meant by "a connection," (*b*) by its "strength" and (*c*) by "a satisfying (or annoying) state of affairs." The body of knowledge that has grown around these issues is called learning theory, and, as already mentioned, centers on the problem of what constitutes reinforcement for an organism. For the most part, laboratory analysis has involved animals, and this almost necessarily has led to some misconceptions which are only now beginning to be remedied.

What is meant by a "connection"? Thorndike and many who followed him thought of the memory-storage mechanism simply in terms of the association between situation and response—contiguous events becoming associated solely by virtue of the contiguity of their effects in the central nervous system. There is, of course, some merit in this conception which has guided the thinking of empiricists for centuries. Yet, today, we can spell out in much greater detail just what contiguity involves. The alert reader will already have anticipated—contiguity implies readiness. The processes discussed in the first section *are* those involved in bringing together within the organism, i.e., within the brain, events and situations experienced on separate occasions—and events not so brought together fail to influence.

The mechanisms discussed in the last section are, of course, not the only ones known to function in readiness. Bruner has reviewed the earlier evidence, which has been added to in many ways. For instance, a great deal of work has been done to show that the activity of all receptors, or at least the input channels from them, is directly controlled by the central nervous system. These "gates" allow the organism to be sensitive only to certain excitations—the gates in turn are self-adapting mechanisms, i.e., they are subject to gradual alteration by the very inputs they control. This is true in the case of control over muscle receptors as it is for others, thus actions are guided much as are perceptions: responses to situations do not become simply associated; readiness is necessary as well.

In line with these facts, the fundamental neural organization in control of the association between stimulus and response can no longer be conceived as a reflex arc. On the basis of many new neurological facts, the suggestion has been made that the reflex arc be replaced by a feedback unit which involves (*a*) a *Test* of readiness with regard to the input, (*b*) an *Operation* that seeks to match the test, (*c*) a re-*Test* to see whether match has been accomplished, before (*d*) *Exit* from control is effected. This TOTE mechanism is ubiquitous—and, as will become clear in the last section of this presentation, it is essentially a modified homeostat, a mechanism which can control the very input to which it is sensitive. TOTEs are conceived to be arranged hierarchically into Plans, the antecedents of actions. And structurally Plans are nothing more than programs, similar to those that guide the operation of computers—well-worked-out outlines such as those used in programed texts and teaching machines. George Miller, Eugene Galanter, and I have already detailed the importance of this new structural view for dealing with some of the persistent problems in psychology. There will be more to say about homeostats, TOTEs, Plans, and programs later on—here the point is that contiguity (association) has *structure*.

This structure is first of all the structure of readiness, of expectancy—of processes such as habituation and redundancy reduction. The problem of association, then, is the problem of readiness which was outlined in the last section. There is no reason at this juncture of our knowledge to treat Thorndike's "connection" separately from his "readiness." The two can no longer be usefully distinguished.

What then can be meant by the "strength of a connection"? Thorndike defines this in terms of the probability of recurrence of a response in a situation—a definition adopted by Skinner to describe the effect of reinforcement. Operationally, therefore, strength of a "connection" is strength of a response in a situation. And response strength has recently become an important focus for learning theory.

Animal experimenters are beset by the difficulty that their subjects have a limited repertoire of "the familiar" to engage in the experimental procedure. Reinforcement in animal experiments has, therefore, been largely in terms of food reward or mild electric-shock punishment. A large body of evidence on the usefulness of these reinforcers was accumulated to the point where learning theorists believed that all behavior modification rests, in the final analysis, on the use of such rewards and punishments. More of this in a moment. But recently this simple notion was found to be inadequate to handle the results of even these same animal experiments. Learning theory faced an impasse. The impasse was this: response strength, i.e., the probability that a response should recur in a situation, ought, according to learning theory, to be proportional to the occurrence and immediacy of appropriate reward and inversely related to the effort expended to obtain that reward. But experimental evidence had accumulated to show that "common assumptions underlying learning theory failed to give an adequate description of changes in response strength." In fact, this evidence suggested "that the variables of reward, temporal delay, and effort may have just the opposite effects from those predicted by the assumptions. . . ." The quotations are taken from a recently published monograph by Lawrence and Festinger. The authors present their evidence that under conditions of *non*-reward, in situations where reward had on earlier occasions been experienced, the strength of response is greater when the experienced rewards had been few, delayed, and obtained with considerable effort. Festinger had already found these same relationships effective in guiding the behavior of human subjects and had proposed that a state of cognitive dissonance (between expected and realized rewards) is set up in the organism when expectations are not met. The organism tries, under the new circumstances, to reduce dissonance "by converting the consequences of his actions into something that justifies the action or he can change his behavior so that it becomes consonant with the consequences experienced." In other words, he can try to alter his expectations or his behavior in such a way that the two again become consonant.

It was of interest to me that the increase in response strength described to occur in these circumstances showed similarities to that observed in addiction. It is common knowledge among morphine addicts that very often the strength of the addiction is proportional to the amount of endeavor required to obtain the drug. (In fact most patients who have had morphine therapy and go through withdrawal symptoms when treatment terminates have an understandable aversion to the drug.)

The question raised by the experiments and observations of dissonance and addictionance is the central one for education: what is the nature of the process of reinforcement? Clearly, rewards external to the materials explored during learning are effective. Grades have their place in school, just as do food rewards in animal learning experiments. But the same impasse is reached in education as is reached in learning theory. Effort, delay, and spacing of reward are known to improve performance. The suspicion is therefore raised that grades and other extrinsic rewards signify something; i.e., give information to the rewarded about something else, something more basic.

There is an example which points up the signifying role of extrinsic reward in an unforgettable manner. My own work has proceeded in large part with the aid of monkeys. These animals are endowed with large pouches in their cheeks into which stores of food can be put for use at a more convenient time. When, in a problem-solving situation, some monkeys make a correct response signified by a reward, they pop the peanut into their food pouch. When, on the other hand, they make an error and there is no reward, they will very often put their hand to cheek, push, and munch with relish their earlier-gotten gain. This never interferes with learning (by comparisons in scores achieved by these monkeys and others with other habits).

Further, a monkey who is doing well in learning a task bounces with zest into the testing apparatus; one whose mastery is failing for the moment droops and is difficult to transfer from his colony cage. Nor can food-reward alter this demeanor. Conversely, I have given as many as fifty trials at a time to monkeys whose food pouches are filled, who are holding peanuts with both feet and one hand, and who are sated. These animals literally will throw peanuts over their shoulder and so free one hand to get on with the problem. And we have, of course, all observed many, many students who "eat up" course material rather than good grades.

There is also no question that teaching machines and programed learning, by their step-wise guides to achievement, have provided a technique for maintaining performance in a problem-solving situation. Whether this will amount to more than an "addiction" probably depends on the way in which these teaching aids are used, not on the technique itself. However, there is a most important fundamental contribution to education in the technique which must not be missed. Programed texts and teaching machines implicitly recognize the significant aspect of reward: reinforcement is constructed through rewards intrinsic in the material to be learned. Each item of information gained values the next step in the sequence of operations.

But this is ahead of the story. The relation of information and value is taken up in the next section. Here, the point is that rewards signify something, something basic and intrinsic in the learning process. Thorndike called this something "a satisfying state."

What, then, constitutes satisfaction? For a time, neuropsychologists thought they had found the answer. And a partial answer it is, for the experimental results give some important clues to the solution of the puzzle. The experimental findings were that animals would work to turn on a minute electric current delivered to certain parts of their brains. This was immediately hailed as a discovery of "the pleasure center"—conservative physiologists suddenly found themselves to be hedonists. But further consideration showed that the problem had only been pushed back a step—to be sure, the brain was involved, and only parts of the brain at that. But through what mechanism was the self-stimulation effect produced? Why was electrical self-stimulation reinforcing? Just what is the nature of reinforcement? And we are back to the initial question.

Nonetheless, these discoveries did leave a clue and provided a handle to the problem: the locations in which these self-stimulations were effective were systematically explored—they are all within the core of the brain substance. Of special interest is the fact that the forebrain placements of the self-stimulation electrodes fall within a system of structures known as the limbic formations. And much work has been done toward finding out what these limbic structures do. The most recent findings supplement earlier ones to the effect that, when parts of the limbic brain are removed, animals have trouble learning to execute behavior sequences. For instance, a monkey is asked to solve the problem of pushing on windows in which numerals are displayed. Normal monkeys can be taught to push first a 4, then a 6; or first a 3, then a 5, then a 7, even though these numerals appear in random order in as many as sixteen different windows. Monkeys who have had part of their limbic brain (the hippocampus) removed on both sides experience great difficulty with such a task. (Control operations that remove other parts of the forebrain do not have this effect—with one exception: i.e., when the anterior part of the frontal lobe is injured, the part made infamous by the lobotomy procedure.)

Somehow, therefore, the problem of reinforcement and the problem of behavior sequences are tied together—if in no other fashion than that both depend on some common neural mechanism, and that is a great deal. But there is more. As already noted, Skinner in his definition of reinforcement, adopted Thorndike's "increased probability of *re*currence of a response." *Re*currences occur in sequence. Further, in animal experiments all events that increase the probability of recurrence of a response are *not* called reinforcers. Cues, events that antecede and guide action, share this property. Only those events *consequent* on action, the consequences of actions, are called reinforcers. And such events have been shown by Skinner and his collaborators to exert their control over behavior not so much singly but by the schedules of their appearance—i.e., reinforcers occur as *sequences*. The organism must be ready (i.e., shaped) to respond to the reinforcing events.

These sequences have their effect on behavior by appearing contiguously with that behavior. This is contiguity, but contiguity as we have now come to understand it. Events reinforce only when they occur contiguously—i.e., in context—when the organism is ready to respond to them. Reinforcers are, therefore, truly the *consequences* of actions—sequences of events occurring in context.

For another occasion I spelled out in detail the experimental foundations that led to this view and its ramifications throughout the problems of motivation. The scope of the issues involved can be sensed from the section headings of this other work, which read: I. "A structuralist looks at operant conditioning"; II. "The structure of contiguity—some psychophysiological facts"; III. "Drive structures and the real CNS"; IV. "Performance theory: addictionance and effectance"; V. "Perceptual performances: reinforcement as information processing"; and VI. "The anatomy of happiness." All of what is said there is of relevance here and I am sorely put to the task of selection: perhaps you will find in this presentation a sufficient sample to engage your interest to pursue the full manuscript.

My answer to the questions of what produces response strength, what is satisfying, stems thus directly from the observations we have been pursuing. Learning theorists using animals were led to believe that the "goads" to behavior (to use George Miller's term) were the drive stimuli which originate in an organism's physiological need states. But effort and hustling, delay and sparseness of reward, are also found to increase response strength under certain circumstances.

Could it be that under these circumstances activity per se is rewarding? This makes little sense, for it would not account for the difference between, say, hustling and unordered, random hyperactivity. And here we may have a clue: could it be that ordered activity per se is rewarding? And further, what can be meant by "ordered activity"—certainly not patterned muscular contractions, since these are equally manifest when we observe random activity. No, clearly when the *consequences* of action become orderly (consonant), i.e., sequences of events appearing *in context*, then and only then is activity ("judged") rewarding, i.e., reinforcing.

The suggestion is that reinforcement is the expression of an organism's tendency toward orderliness; that satisfaction results when a degree of orderliness has been achieved. There is good reason to suspect that the central nervous system is so constructed that order is imposed on its inputs if this is at all possible; if it is not, search continues. Mathematical models that simulate the neural process have given a variety of related and precise expressions to this mechanism. These need now to be put to test in the neurophysiological laboratory. Techniques are available, and data should be in hand during the next few years.

At the moment, the analysis of reinforcement here pursued has shown that the process of satisfaction is to be conceived as *intrinsic* to the material ordered and *intrinsic* to the construction of the nervous system. Education so conceived is truly a process of *e-ducere*, the art of bringing out this tendency to orderliness.

At what points is orderliness sufficient to satisfy? This question is intimately related to another: how is learned material remembered? Earlier the evidence was presented to show that the neural mechanisms, those important to learning and those involved in retention, differ. Perhaps satisfaction results when learned material is not just retained but is remembered in the sense opposite to "dismembered," and therefore as a remaking into context—when acquired information places a value on new inputs. But before these conceptions of the intrinsic nature of reinforcement and satisfaction can come clear, we must more fully explore what is meant by "the tendency to become orderly." And so we turn to the important topic of structure.

Transfer and the Problem of Structure

> It goes without saying that man begins as a part of physical and animal nature. In as far as he reacts to physical things on a strictly physical level, he is pulled and pushed about, overwhelmed, broken to pieces, lifted on the crest of the wave of things, like anything else. . . . That appetite is blind, is notorious; it may push us into a comfortable result instead of into disaster; but we are pushed just the same. *When appetite is perceived in its meanings, in the consequences it induces, and these consequences are experimented with in reflective imagination, some being seen to be consistent with one another, and hence capable of coexistence and of serially ordered achievement, others being incompatible, forbidding conjunction at one time, and getting in one another's way serially—when this estate is attained, we live on the human plane, responding to things in their meanings. A relationship of cause-effect has been transformed into one of means-consequence.* Then consequences belong *integrally* to the conditions which may produce them, and the latter possess character and distinction. The meaning of causal conditions is carried over also into the consequence, so that the latter is no longer a mere end, a last and closing term of arrest. . . . Its value as fulfilling and consummatory is measurable by *subsequent* fulfillments and frustrations to which it is contributory in virtue of the causal means which compose it [italics and underscoring mine].[8]

The question of how to teach is intimately interwoven with the problems of the transfer of training. How can education be conducted so that transfer is maximized? Just how is transfer accomplished? Thorndike in his chapter on the "Influence of Improvement" focused on the identification of "similar elements" between the material learned and the new situation. Where do we stand today?

Return for a moment to the effect of brain operations on problem-solving behavior. Compare two lesions, both of the temporal lobe of the cerebral hemispheres. One lesion involves the limbic formations of the temporal lobe (a part of the brain already discussed in the last section); the other ablation involves the cerebral mantle, the newer cortex of temporal lobe in portions of what is usually called the "association" area. The problem is the following: the animals, monkeys, are asked to choose between two small doors hung on a black background. The doors are painted grey and are identical except that one is darker than the other. These doors are easily inter-

8. Dewey, *Experience and Nature, op. cit.*, pp. 300–301.

changed and exchanged from trial to trial in random order between the two placements. On each trial the monkey is allowed to open only one door. When he chooses the darker grey he finds a peanut in the opening; when he opens the other door he is faced with an empty tray. Unoperated monkeys learn to choose the darker door after a couple of hundred trials or so. The monkeys with the limbic system lesions learn with equal facility. Those with the lesions of the newer "association" cortex have great difficulty, however. As already noted in the last section, this difficulty is more related to remembering what they had learned in previous session than to learning per se. However, finally they do perform the task as well as the others. Now the problem is changed. Every fifth trial two new doors are hung in place of the others. One of these new doors is the same dark grey as the previously rewarded one; the other is darker yet. Placement is again random. This time a peanut is put behind both doors. Note that only every fifth trial is set up this way—for the other four, the lighter pair of doors continues to be used, and only the one dark door has a peanut behind it.

The expectation is that normal monkeys will transfer their choice of "push the darker door" to the new situation, the fifth trial in every series. And normals do just this. So do the animals with the "association" cortex ablations. Only the monkeys with the limbic lesions fail to transfer. They choose the test doors on a fifty-fifty basis; they treat the test trials as a completely new situation.

This failure to transfer is not related to a change in the way these animals generalize among the stimulus aspects of a situation. A test of stimulus generalization shows these monkeys to perform as do their controls. It is the "association" cortex ablation that produces greater generalization—i.e., a wider range of physically related stimuli is now treated as identical. In other words, retention and transfer have been clearly dissociated. And the brain systems involved in transfer are those already shown to be importantly concerned in the process of reinforcement.

So once again, it is necessary to turn to reinforcement, consequences of behavior. As suggested in the last section and detailed in the presentation already mentioned, reinforcement results when events subsequent to behavior become contextually related to the behavior, i.e., become con-sequent. Context, that is to say, readiness, can be supplied by a variety of stimulus events. In animal experiments the subject is usually deprived of food or water for a period of time so that the drive-stimuli, excitations that accompany physiological needs, provide context, readiness, for food pellets or sips of water which are scheduled to become available when the "correct" action has been performed. Only recently has it become apparent to practically all experimenters (some had been saying this for a long time) that, to the animal, such reinforcers give information about the correctness or incorrectness of the action in the stimulation: i.e., that reinforcers instruct. *During learning, reinforcers act as instructions; they are informative.*

But animals, even rats, are smart: after a period of isolation, put a rat in a T-maze with one alley of the T painted white, the other black, with a mate placed at the end of the white alley. No normal rat runs down that black alley more than once or twice. He has learned to find the female in one trial. She has acted as information to guide correct choice. However, her role as reinforcer is not finished. Repeat trials and allow mating to occur, but not every time. Measure his running speed. You will find it to be directly proportional to the number of times mating has taken place. In technical language, *she*, the reinforcer, has, in addition to giving information, *placed a value on his* running speed. *Reinforcers* are thus shown to be *valuative in performance.*

But values indicate readiness, context. How can reinforcement be both informative and valuative? How can they be both context and content? Or better, how do event sequences that are content during learning become context during performance; how is information transformed into value?

The example chosen deals with drive stimuli. In the first section, readiness was discussed in perceptual terms. Needless to say, information is usually thought of as perceived. The information-value problem is, therefore, not limited to cases where drive stimuli are concerned. In fact, the problem is an even more general one. In the last section, the ordering of consequences of actions was found to constitute reinforcement in situations where addiction and dissonance were observed. In that case the consequences of actions had to provide their own order; they themselves had to become the context within which subsequent events would become consequent—

i.e., reinforcing. The question raised was just what is involved in this ordering of consequence: (*a*) When does it occur? (*b*) What constitutes its composition?

As to when it occurs, the following statement by Mace is relevant:

> What happens when a man, or for that matter an animal, has no need to work for a living? . . . the simplest case is that of the domesticated cat—a paradigm of affluent living more extreme than that of the horse or the cow. All the basic needs of a domesticated cat are provided for almost before they are expressed. It is protected against danger and inclement weather. Its food is there before it is hungry or thirsty. What then does it do? How does it pass its time?
>
> We might expect that having taken its food in a perfunctory way it would curl up on its cushion and sleep until faint internal stimulation gave some information of the need for another perfunctory meal. But no, it does not just sleep. It prowls the garden and the woods killing young birds and mice. It *enjoys* life in its own way. The fact that life can be enjoyed, and is most enjoyed, by many living beings in the state of affluence (as defined) draws attention to the dramatic change that occurs in the working of the organic machinery at a certain stage of the evolutionary process. *This is the reversal of the means-end relation in behaviour.* In the state of nature the cat must kill to live. In the state of affluence it lives to kill. This happens with men. When men have no need to work for a living there are broadly only two things left to them to do. They can "play" and they can cultivate the arts. These are their two ways of enjoying life. It is true that many men work because they enjoy it, but in this case "work" has changed its meaning. It has become a form of "play." "Play" is characteristically an activity which is engaged in for its own sake—without concern for utility or any further end. "Work" is characteristically activity in which effort is directed to the production of some utility in the simplest and easiest way. Hence the importance of ergonomics and work study—the objective of which is to reduce difficulty and save time. In play the activity is often directed to attaining a pointless objective in a difficult way, as when a golfer, using curious instruments, guides a small ball into a not much larger hole from remote distances and in the face of obstructions deliberately designed to make the operation as difficult as may be. This involves the reversal of the means-end relation. The "end"—getting the ball into the hole—is set up as a *means* to the new end, the real end, the enjoyment of difficult activity for its own sake.[9]

9. C. A. Mace, "Psychology and Aesthetics," *British Journal of Aesthetics*, II, No. 1 (January, 1962), 10–11.

A somewhat similar statement by White of the role of progressive achievement of competence as an important guide to behavior is encompassed in the idea of effectance.

> Effectance is to be conceived as a neurogenic motive, in contrast to a viscerogenic one. It can be informally described as what the sensory-neuro-muscular system wants to do when it is not occupied with homeostatic business. Its adaptive significance lies in its promotion of spare-time behavior that leads to an extensive growth of competence, well beyond what could be learned in connection with drive-reduction.[10]

There is, then, no question of the importance of this reversal of means-end, of content and context, of information and value. It occurs at some stage when order achieved among consequences overrides prior contextual orders.

How is this accomplished? What constitutes the composition of order? That is the problem to which an analysis of the structure of the reinforcing process must be addressed. Bruner, in his influential report of the conference on the process of education, describes the act of learning as follows:

> Learning a subject seems to involve three almost simultaneous processes. First there is acquisition of new information—often information that runs counter to or is a replacement for what the person has previously known implicitly or explicitly. At the very least it is a refinement of previous knowledge. . . .
>
> A second aspect of learning may be called *transformation*—the process of manipulating knowledge to make it fit new tasks. We learn to "unmask" or analyze information, to order it in a way that permits extrapolation or interpolation or conversion into another form. Transformation comprises the ways we deal with information in order to go beyond it.
>
> A third aspect of learning is *evaluation:* checking whether the way we have manipulated information is adequate to the task.[11]

Interestingly, these three stages mirror roughly three stages that can be distinguished in the intellectual development of the child. Preschool children are mostly occupied with acquiring information —their concern is to "manipulate the world through action" and thus

10. R. W. White, "Competence and the Psychosexual Stages of Development," in *Nebraska Symposium on Motivation, 1960,* p. 103. Edited by M. R. Jones. Lincoln: University of Nebraska Press, 1960.

11. J. S. Bruner, *The Process of Education,* p. 48. Cambridge: Harvard University Press, 1962.

to establish "a relationship between experience and action."[12] Experiences, the consequences of actions, are placed into the context of the actions that brought them about or into the context of drives and perceptions. "What is principally lacking in this stage of development is what the Geneva school (Piaget, Inhelder, *et al.*) has called the concept of reversibility."[13]

The second stage involves this concept of reversibility. The child is now able to grasp the idea that quantity can be conserved even when things are partitioned.

If marbles, for example, are divided into subgroups, the child can grasp intuitively that the original collection of marbles can be restored by being added back together again. The child tips a balance scale too far with a weight and then searches systematically for a lighter weight or for something with which to get the scale rebalanced. He may carry reversibility too far by assuming that a piece of paper, once burned, can be restored.

. . . the child develops an internalized structure with which to operate [on his experience]. In the example of the balance scale, the structure is a serial order of weights. . . . Such internal structures are of the essence.[14]

Finally, the child develops the ability to evaluate, to operate on hypothetical propositions, to value values, often by returning to testing and checking, i.e., by again gathering new information.

The second stage of the act of learning, the stage when the child is using to the maximum this capacity for reversibility, is of interest here. What is the internalized structure that allows this reversibility to occur and with it the ability to transfer, thus providing an organism the grasp of constancy, of invariance? (Inhelder: "The most elementary forms of reasoning—whether logical, arithmetical, geometrical, or physical—rest on the principle of the invariance of quantities: that the whole remains, whatever may be the arrangement of its parts, the change of its form, or its displacement in space or time."[15]) What internalized structure allows transfer among palpably different experiences to take place?

In the last section a hint was given about the nature of this structure: the suggestion was made that it is constructed as a hierarchically nested series of test-operate-retest-exit units, a plan, a

12. *Ibid.*, p. 34.

13. *Ibid.*, pp. 34–35.

14. *Ibid.*, pp. 36–37.

15. *Ibid.*, p. 41.

program; homeostats set in the context of other homeostats and, thus, contextually biased by them and, in turn, biasing. What is the evidence?

The idea of homeostats was proposed by Cannon to account for the exquisite control exercised by the hypothalamus in the core of the brain over the internal environment of the organism. Since Cannon's time the structure of this homeostat—or better, of the several homeostats that make up the regulating mechanism—has been clearly established. Each homeostat is composed much as is the thermostat that regulates the temperature of our homes. There is a sensitive element, a receptor (e.g., the thermostat's thermocouple), there is a connection with an apparatus that can produce the substance to which the sensitive element is sensitive (e.g., the furnace produces the heat which is sensed by the thermocouple) and these are so arranged that the producing device is switched off when the amount of the substance rises above a certain point and switched on when the amount of the substance falls below the point. A great deal of detail is known about the homeostatic devices that control respiration, temperature, eating, drinking, and sexual behavior.

These physiological mechanisms provided the model for engineers who wanted to build devices that could regulate the input to which they were sensitive. As long as these inputs were conceived as substances, the applications of the model were limited. During the past world war, however, several of Cannon's pupils (e.g., Wiener and Rosenblueth) extended the model to bands of the energy spectrum other than heat; cybernetics and information theory were the result.

As already indicated, in the organism as well, the homeostat model applies more generally. The TOTE was made necessary when the central control over muscle receptor function became an established fact. And its applicability to sensory as well as to motor function has been well documented.

So why has this homeostatic model not taken hold completely—what is wrong with it? The model was designed (both with respect to the organism and in engineering) to track and to maintain equilibria. The very problems that concern educators and psychologists are not touched by such a "static" structure, wonderful though it may be. Psychologists have been concerned with learning, with drive, with motivation; educators with how to teach, to guide, to motivate. Change, not complacency, is at stake.

An almost forgotten device comes to their aid. Every thermostat is equipped with a gadget, usually a little wheel, by which the thermostat's set point can be altered. This is the thermostat's *bias*. With it, wonderful, and horrible, things can be accomplished. Make a sudden change on the setting and the stable system that was a temperature-controlled environment begins to fluctuate and oscillate for a period around a new set point. Or, make a continuous small change of the setting and one can, unless other safeguards have been built in, blow up the furnace through continually accruing heat production. Manipulate the bias and the homeostat becomes anything but a purely equilibrial device. Complacency is gone.

Is there any evidence that is consistent with the view that the body's homeostats are biased? I have suggested elsewhere that the results of electrical self-stimulation can be so conceived. Certain predictions followed: self-stimulation should be obtainable not only when drive systems are biased by the excitation but also when the electrodes are placed in motor systems. This has been experimentally demonstrated. The suggestion is that the organization of action resembles the biased homeostat, the structure of drives. It follows that the bias of the neural mechanism in control of action should be resettable, much as is the bias of the drive homeostats, to produce the phenomenon of self-stimulation. This has been accomplished by John Lilly. Prolonged trains of excitation (subliminal to those that would produce movement) were delivered to the precentral motor cortex whenever the lever was depressed by the subject (a monkey). Lever pressing had to be placed so that the on-off nature of the excitation could be maintained. The monkey learned to do this, however, and spent many (may I say "happy"?) hours at this occupation.

There is, thus, good reason to believe that biological homeostats, just as mechanical ones, are settable, that they are equipped with the mechanisms that can bias them. The biasing operation is conceived to take place as follows:

Homeostats can be hierarchically arranged. The blower on the home-furnace of a hot air system is controlled by a thermostat separate from, but subordinate to, the main thermostat. There is some evidence that the food-appetitive and general activity mechanisms of the organism are both contained within the larger regulation of basal temperature. But, I believe this simple statement of a hierarchical relationship does not give a full account of the process which is of concern here. What seems to happen is that there is a true reversal of means and ends, of context and content, of bias and the mechanism biased. Differentiation can take place in the biases placed on the mechanism—the temperature of a home will be controlled by several thermostats, each of which biases the main mechanism but is in turn biased by it. This complex yet orderly interrelation among subsystems and system achieves stabilities beyond those possible for the simpler systems. The suggestion is that the biased homeostat becomes differentiated, mainly through differentiation of its bias, perhaps because of inherent imperfections. These imperfections must be in the control the mechanism has over the variables to which it is sensitive. This poses a paradox—for differentiation occurs most readily when such control appears to be accomplished. But just at these junctures, increased sensitivity is also achieved: viz., the thermostatic system that has allowed temperature to vary between 65° and 75° F. is insensitive to temperature changes of one or two degrees. When the system is sufficiently stable to control temperature at 70° it becomes exquisitely sensitive to a two-degree change. And these new sensitivities cause the system to react where it would not have done so on prior occasions. Thus, though this is a structural, even a homeostatic, view of the behavioral process, its design certainly does not lead to stagnation.

What operations lead to the differentiation of biases? As already noted, one of the conditions for differentiation is the achievement of a stable level of control over input. Here may be a clue. The same limbic systems that play such an important role in electrical self-stimulation and in the learning of sequential tasks may be involved in the following manner: Specifiable electrical changes have been recorded in the limbic systems (the amygdaloid complex) whenever the organism has been exposed to a novel event or one that has meaning in terms of reward and punishment. These electrical changes subside once the organism is familiar with the event, unless another part of the limbic systems (the hippocampal formation) has been ablated, in which case the electrical changes continue to occur when this or any other event takes place. In addition, the amygdaloid complex of the limbic systems has been shown necessary to the establishment of electrocortical conditioned responses. The suggestion has been made that the hippocampal formation inhibits (perhaps by way of the reticular core of the brain stem) the succession of unrelated inputs to the amygdala that might occur and so allows this structure to maintain the neural activity necessary to the conditioning process. In a conditioning or learning situation, electrical changes are recorded from the hippocampal formation during the initial trials. Later, no such changes accompany successful action; they occur only when errors are made.

Very careful but complicated analysis of the electrical activity recorded during learning of a visual discrimination has led Adey to venture that phase relations between wave patterns recorded from the deeper and more superficial portions of the hippocampal cortex change as a function of task performance. Early, while many errors are made, the activity recorded from the deeper layers of the hippocampal cortex precedes that from the more superficial layers; later, when performance contains many error-free runs, the reverse is the case. Input to the deeper layers is from other core structures of the brain; input to the more superficial layers is from the adjacent entorhinal and cingulate cortex.

Despite the preliminary nature which these data must have because of the state of the computing art in neurobiological science, it nonetheless strikes a responsive chord. This is especially so since Flynn, MacLean, and Kim concluded in their pioneering work on the effects on behavior of afterdischarges produced by electrical stimulation of the hippocampus:

> Is it possible that the neural perturbations remaining in these structures after sensory stimulation allow a more ready association of two temporally separated events than is possible in the neocortex, where one does not see a comparable phenomenon?[16]

In addition, Freeman, using an entirely different technique, has reported a somewhat similar "comparator" process to account for electrical phenomena recorded from the pyriform cortex (cats) just prior to the performance of a conditioned response.

16. J. P. Flynn, P. D. MacLean, and C. Kim, "Effects of Hippocampal Afterdischarges on Conditioned Responses," in *Electrical Stimulation of the Brain*, p. 386. Edited by D. E. Sheer. Austin: University of Texas Press, 1961.

The proposal is that the limbic systems serve in reversing, as a function of experience, the context-content relationship between drive stimuli and other reinforcing events. There is some evidence that other than drive stimuli are involved in this limbic system function. The stimuli in question may perhaps be only those close relatives of drive stimuli, such as olfaction and taste; but behavioral evidence (deficits on alternation tasks that follow hippocampal and cingulate resections) suggest that the stimuli affected are of a still wider range.

If, indeed, this evidence holds, a first step will have been accomplished in unraveling the mechanism by which bias differentiates. The hippocampus, by inhibiting the succession of unrelated inputs, allows continuing activity of the amygdala to stabilize the system. The stable system is then sensitive to alterations in context-content relationships. In the experiments mentioned, context is initially provided by drive stimuli, content by the consequences of action; after these consequences compose a structure of their own they vie for the context position and finally win out—perhaps on a simple event-rate basis. Or it may be that reversal takes place when more order is achieved among the consequences of action than exists among drive stimuli. In any case, the reversal has been observed to occur.

This is as far as the analysis based on neuropsychological experiment can now be pushed. It tells us that a mechanism exists by which reversals of content and context can occur in at least one and perhaps two locations in the brain (Adey and Freeman). Because of the similarities to this process encountered in the development of perceptual and motor skills, precise questions can be put to the laboratory with the aim to identify, in other locations, this mechanism for reversal. For it is clear that reversal—of content-context, of means with end, of information and value—is the fundamental transformation necessary for serial ordering of achievement.

As noted in the last section, the efficacy of *in*-struction by teaching machines and programed texts may, in large part, be attributed to the limits placed on the sequences of operations that must be endured before the information gained at one step comes to place a value on that gained in the next. The danger is that programs poorly constructed will determine meaning "in terms of consequences hastily snatched at and torn loose from their connections"—and so "the formation of wider and more enduring ideas" will be prevented. At the moment, the only safeguard against this that might be suggested is that the reinforcing structure intrinsic to the material in some way match the intrinsic reinforcing structure of the organism. Continuous differentiation of the context, the valuative process, must be the aim. This is accomplished through the test-operate-retest-exit process, guided by inputs (information) administered in such a way that exit is achieved only after many sub-TOTEs have been brought into operation. To prevent runaway operation, however, temporary stabilities must be achievable—only when a certain information pool has been brought under control can new sensitivities be engaged. Successful programs are, of course, constructed in just this manner by intuitive teachers. Research is sorely needed, however, to make explicit the "natural" locations of equilibria in subject matters as well as in the subjects to be exposed to them.

Given these precautions, and thus keeping the whole structure that has been developed at any moment clearly in focus, there is little merit in the accusation that because of their routine character, teaching aids (programs) fail to meet the most urgent requirement of education: to produce *creative* people. We harbor many misconceptions about creativity. According to the most prevalent misconception, discoveries and inventions arise out of the blue. But the contrary is the case. In reality, discoverers make their discoveries through what they already know: they match the unfamiliar against a thoroughly incorporated body of fact. Columbus, for example, knew a great deal about navigation. He knew the assumed boundaries of the flat world and what could be expected if, as some people suspected, the world were really round. But other explorers had to repeat Columbus' feat before the discovery of America was admitted (should we say as context?) to the thinking of all sailors.

The inventor achieves novelty within the bounds of certainty. He comes upon, finds, only when properly prepared for the finding. The term "inventor" derives from the same root as "inventory." Edison expended his "ninety-nine percent perspiration" by taking stock of the boundaries of known electrical science. Only then, at those boundaries, did the new procedures strike him as plausible. The inventor innovates, as when, like Edison, he substitutes tungsten for iron to make an electric light bulb from an electric heating element.

The construction of a great symphony follows familiar lines: the rules of theme and subthemes, beat and counterpoint, form and movement, must all be thoroughly mastered before creative composition can begin. Beethoven created music by taking discipline even farther than its already complex structured limits. He sensed nuances where none had been sensed before. He prepared musical programs more complicated than seemed possible.

And what of the poet, supposedly the freest of free souls? Perhaps more than any creator, he is constrained by the known rules within which novelty can be expressed. Shall he choose iambic pentameter, rhyme or alliteration, couplet or sonnet? He must carefully tend the meaning of a word so that where several meanings are possible each is enhanced by the context in which the word appears. In such a wealth of rules and orderliness lies the creativity of the poet as well as his freedom. For freedom is not anarchy. Real freedom is intelligent, knowledgeable choice and rises out of order when order achieves sufficient complexity.

Thus, man's brain shapes freedom. Through ever more effective innovations in the rules for social interaction, man's brain frees him from fear. Through ever improving methods of production and distribution, man's brain frees him from want. Through ever growing powers to perceive and plan, man's brain frees him for love and fun.

Man's brain does all this and always has. We share the promise that it always will: though slowly and by steps with pain. For that is how we learn.

Thus to be conscious of meanings or to have an idea, marks a fruition, an enjoyed or suffered arrest of the flux of events. But there are all kinds of ways of perceiving meanings, all kinds of ideas. Meaning may be determined in terms of consequences hastily snatched at and torn loose from their connections; then is prevented the formation of wider and more enduring ideas. Or, we may be aware of meanings, may achieve ideas, that unite wide and enduring scope with richness of distinctions. The latter sort of consciousness is more than a passing and superficial consummation or end: it takes up into itself meanings covering stretches of existence *wrought into consistency*. It marks the conclusion of long continued endeavor; of patient and indefatigable search and test. *The idea is, in short, art and a work of art. As a work of art, it directly lib-*

erates subsequent action and makes it more fruitful in a creation of more meanings and more perception [italics and underscoring mine].[17]

Bibliography

This manuscript has pulled together work that, in the author's opinion, has direct bearing on education. He has detailed the explicit references to this work in other contexts. Here, therefore, these other manuscripts are suggested as key primary references, together with some others that would serve in a similar fashion. The assumption is that a program of reading initiated in this fashion would acquaint the reader pretty well with all primary sources of current ferment and endeavor on this important and exciting frontier of knowledge.

ON READINESS

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