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FORMALIZATION AND CLARIFICATION OF A THEORY OF LEARNING*[1]

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A. INTRODUCTION

In order to test any theory and determine the revisions necessary to bring it into accord with the empirical world, and in order to apply the theory in control and prediction of events, rigorous deductions from the theory are prerequisite. Whatever aids making these deductions is, then, of both theoretical and pragmatic importance. One facilitating factor is clear statement of the fundamental theoretical generalizations.

While writing with great logical consistency, Guthrie never formally presented his postulates and definitions. The basic principles can be induced from his publications; but often that is all, the fundamental aspects of the theory usually being rather more implicit than explicit.

This paper is an attempted remedy—attempted partly because of the considerations mentioned in the opening paragraph and partly because advances in understanding any area of investigation seem highly dependent upon having tightly formulated theories at our disposal. Apparently also, having a multiplicity of such theories aids advancement of any science.

Presented herein is an explicit statement of various postulates and definitions apparently constituting the basis of this theory, some of their implications, and the derivation of eight theorems.[2] The theory is reflected only as it has been presented in the past and stands at present. It is highly probable that in light of further observation, the postulates may need to be

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[2]These postulates "apparently" constitute the basis of the theory because (*a*) they are, as mentioned, largely a matter of inference; and (*b*) it is entirely conceivable that various other hypotheses, consistent too with Guthrie's statements (but which may be deduced from the following postulates), could be taken as postulates instead of those selected, and could be used as bases for deducing some of the present postulates as well as a still greater variety of theorems. If this is the case, such a set would be preferred to the present combination. However, of the various possibilities I have tried, the four given below proved the most satisfactory combination.

revised or supplemented by additional postulates to mediate deduction of certain established (or to-be-established) empirical phenomena.[3]

B. Postulates

1. *Postulate 1: Principle of Association*

(*a*) Any stimulus-pattern which once accompanies a response, and/or immediately precedes it (by ½ seconds or less), becomes a full-strength direct cue for that response. (*b*) This is the only way in which stimulus-patterns not now cues for a particular response can become direct cues for that response.[4]

The proposition that association of a response-pattern and stimulus-pattern is established when those stimuli accompany the response is repeatedly presented in Guthrie's writing, for example, in 1930, p. 412, lines 28-29; 1933b, p. 355, lines 18-21; and p. 365; 1934a, p. 200-202; and these two quotations:[5]

> "What we can predict is that the influence of the stimuli acting at the time of either satisfaction or annoyance will be to re-establish whatever behavior was in evidence at the time that the stimuli were present. . . . The substitute stimulus is probably always coincident with the response though not with the original stimulus" (1934b, p. 454-455).
>
> "The stimuli present as the response occurs are the future cues for the response" (1935, p. 33).

That Guthrie holds this is the *only* way an S—R association may be set up and also is fundamental to all learning, is evinced by his discussions of serial learning in maze situations and inolving nonsense syllables (1933b, p. 361-364; 1936, p. 111 ff.), so-called trial-and-error learning, as for instance in puzzle boxes (1934b; 1935, p. 187 ff.: 1937a; 1937b and 1938b—with Horton; 1942a), instrumental conditioning (1936; 1937a; 1942b, p. 107), the establishment of voluntary responses (1937c; 1938a), the effect of re-

[3]For example, there probably will need to be some indication of which physical forces are most apt to be stimuli in the psychological sense defined below, when and if that is determined. This is, of course, an aspect of the old problem of the prepotency of stimuli and attention, as well as of the newer problem of the nature of patterns; it is a possible lack of completeness not peculiar to any one theory.

[4]To have any stimulus-pattern become a direct cue for a specified response, Part *a* states that contiguity or near contiguity of the stimulus-pattern and response is a sufficient condition, and Part *b* states that it is a necessary condition.

[5]The documentations given herein are not all the relevent sections of Guthrie's treatises, but they are representative in that no statement in the original sources is obviously inconsistent with those present here. These few are given partly to illustrate that these postulates express views forming an integral part of Guthrie's theory, partly to clarify the meaning of the postulates, and finally to show ways in which they may be used.

ward and punishment in habit formation (1934b; 1935, p. 148 ff.; 1940a), Katona's dichotomization of learning ("repetition" with conditioning being included therein, vs. "understanding"—1940b, p. 822, lines 33-40), and by such comments as:

> "This acquisition, when it does occur, is the fundamental mode of learning" (1930, p. 416, after a statement that if stimuli accompany a particular response, a new association between the two is acquired).
>
> "The only generalization applicable to all learning that appears to me acceptable is the general principle of association" (1942b, p. 113), essentially the same point as that elaborated in 1938a, p. 33 ff, and 1942a, p. 23.
>
> "That we learn is insured by the association of a stimulus with a response" (1946a, p. 10).

The lucid discussion following the final quotation is to the effect that if a certain stimulus-pattern is present while a response is made, a learned association results; and furthermore, that not only is this a *sufficient,* but also the *necessary* condition of learning (although it is not sufficient, of course, to demonstrate that learning has occurred, since that requires an additional presentation of the newly conditioned stimulus-pattern without the US). This is precisely the same point made in 1946b, p. 286 paragraph 5.

Finally, the *strength* of the association between the stimulus-pattern and the response-pattern is held to be *established fully* through *once* pairing the two (cf. 1930, p. 419, lines 34-37, and p. 420 lines 13-19; 1934a, p. 205, lines 9-13; 1935, p. 98, lines 26-30; 1942a, p. 30, lines 33-34; 1946c, p. 8, line 1, and p. 41, col. 2, lines 3-4).

That this accords with Guthrie's theory is somewhat obscured by his usually combining implications of Postulate 1 (a principle of learning) and Postulate 3 (a principle of performance), and sometimes of Postulates 2 and 4 as well. Thus we read:

> "A stimulus pattern that is acting at the time of a response will, if it recurs, *tend* to produce that response" (1942a, p. 23). (Similar statements appear in 1935, p. 26, lines 2-5, and 1938a, p. 37, lines 28-29, as well as many other places.)

Such statements may be a bit misleading as they do not mean the association is only partially established when once the stimuli accompany the response.

The statements would be clearer, perhaps, were an explicit distinction made between (*a*) establishing *association* of a response with a stimulus-pattern and (*b*) future *elicitation* of that response by a stimulus-pattern. Now elicitation of a particular response upon presentation of certain stimuli

(e.g., ones of Pattern S_1) depends in theory upon a variety of factors *in addition to* that of whether the response has become associated with S_1 (Postulate 1). Such additional factors are, for example, (*a*) whether all stimuli of S_1 are present at the time specified, (*b*) whether S_1 or a part of S_1 has accompanied some incompatible response in the interim (Postulate 2), (*c*) whether in addition to S_1, the group of stimulus-patterns presented on the trial specified includes also many others differing from S_1 (which often is the case—Postulate 4), (*d*) whether these additional stimulus-patterns are cues for the response-pattern in question (Postulate 3), et cetera.

This aspect of the theory then, as I understand it, is as follows: Through once pairing them, a new association will be established between S_1 and a certain response (say, R_X) and established as strongly as it ever can be. As a result, R_X subsequently would always be evoked by that pattern (*if* presented alone or with other cues for R_X and before intervening counter-learning) even though some other response has previously accompanied S_1 with indefinitely greater frequency. Nonetheless, according to the theory, there is a *tendency* only for R_X to be elicited on future presentations of S_1 due to the other factors of theoretical importance listed in the preceding paragraph. Prediction of what response will be made depends upon observing the stimulus-patterns present at the time (not upon observing merely the presence or absence of one particular pattern), knowing what responses these various patterns last accompanied, and taking this information and the preceding factors into consideration.

2. *Postulate 2: Principle of Postremity*

(*a*) A stimulus which has accompanied or immediately preceded two or more incompatible responses is a conditioned stimulus for only the last response made while that stimulus was present. (*b*) This is the only way in which a stimulus now a cue for a particular response can cease being a cue for that response.

There is frequent reference to this principle, such statements as the ones below being found throughout Guthrie's writing:

> "If the stimulus combination occurs, and the response is prevented by any means, the stimulus combination loses its power to elicit the response" (1930, p. 417).
>
> "An association is continuously destroyed by new associations" (1943b, p. 453), i.e., a stimulus-pattern ceases being a cue for responses formerly made when it is associated subsequently with responses incompatible with the former ones.
>
> "I would not hold that all satisfiers tend to fix the associative connection that has just preceded them. When a satisfying situation involves

> breaking up the action in progress (i.e., if as a result of the "satisfier," some new response incompatible with the former response is made), it will *destroy* connections between the former CR and CS's acting at the time" (1934b, p. 457).[6]

Although Postulate 2a generally has been referred to as a principle of recency (cf. Guthrie, 1935, p. 114; McGeoch, 1942, p. 537; and Spence, 1942, p. 301), there are a number of objections to a continuance of this custom. These objections are outlined below, largely in an effort to clarify the meaning of the present postulate.

(*a*) "Recency" has been used a great variety of meanings, of which the following are examples.

Brown (1846, p. 372) popularized the term for use in reference to the temporal relationship of a given experience to all other experiences, i.e., to the position on the time continuum of any association. This is essentially the same meaning as one given by McGeoch (1942, p. 569): "The time elapsed between initial fixation and a later measure of retention," and used by Hunter (1934), for example.

A modification in Brown's meaning was introduced by restricting "recency" to the temporal relationship existing among associations of various responses to various stimuli (the different stimuli being associated with different responses) when these associations are established in the same general situation. This is the meaning of the term in the "primacy-recency" discussions. "Recency" here is not a question merely of how long ago some association was formed, but rather of which of the various S-R connections established in the same serial learning situation was last in the series. (For example in a series such as this: $S_{1+g}-R_1$, $S_{2+g}-R_2$, . . . $S_{n+g}-R_n$, the connection S_n-R_n is favored over the others because of "recency.") For cases of this usage, see Warden 1924, Jersild 1929, Warden and Cummings 1929.

A further modification is that of Watson (1914) in which "recency" referred to the relationship between various responses made to the same stimulus, e.g., the relationship of S_1-R_1 and S_1-R_2 to S_1-R_3, the last response to S_1 being the most "recent." Here again, how long ago S_1 was encountered is wholly irrelevant. With respect to these matters (but only these), Guthrie's meaning of recency is the same as Watson's.[7]

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[6]For further statements and discussions of Principle 2a, one may consult 1930, p. 420; 1934b, p. 452; 1940a, p. 143; 1942a, p. 26; 1942b, p. 111; 1946c, p. 38 (lines 12-16;) and for more explicit statements of Principle 2b, see 1930, p. 420-422; 1935, p. 121-122; 1940a, p. 145, lines 2-4; 1942a, p. 59, lines 12-21; 1946c, p. 39, lines 3-8, and p. 41, lines 3-8.

[7]The particular distinction between "recency" in terms of time and "recency" in terms of order of occurrence has been made by Hilgard and Marquis, 1940, p. 349.

The difference between the meaning of Postulate 2a and recency in any of the above senses is clear if one considers this case: S_1 has accompanied R_1 x time ago; S_2 has accompanied R_2, x + y time ago; neither S_1 nor S_2 has since been present. According to any of the above meanings of recency, the strength of the association for S_2-R_2 will be stronger than that for S_1-R_1. But it will *not* be stronger according to Postulate 2a—they will be equally strong if neither S_1 nor S_2 has since been present.

Yet another meaning is one of those given by McGeoch: "The time interval between the terms to be associated" (1942, p. 569).

(*b*) Not only are there different meanings of the term, but also markedly different rationales for the various principles.

The first of these to be presented in detail was that of Watson, wherein the principle of recency was subordinated to that of frequency, with the "Law of Probabilities" tentatively being held fundamental to both. His rationale is this: With the appearance of the last (and correct) response, the S-R series is cut short; and thus certain responses, which otherwise might have been made also, are prevented from occurring. Hence, these other responses have a *decreased frequency*, relative to the frequency of those which did occur, and as a result have a tendency to be eliminated from the animal's repertoire. Similarly, since the response which terminates the situation *does* appear (and must invariably do so), it has an *added frequency* of one, and thus an increased probability of re-occurrence. Hence, due to the supposedly relatively greater frequency of the most "recent" response and the theorized positive correlation between frequency and probability of re-occurrence, "recency" may be a factor determining what response will come to be made invariably to a situation. The effectiveness of "recency," according to Watson's theory, is dependent upon the existence and effectiveness of frequency.

Radically different is this rationale, suggested by Guthrie: At the time each response is made in a situation, it is attached to the stimulus-patterns present, and all preceding responses are wholly detached from them (detached as a result of that one pairing in spite of the possibility that in the past those responses accompanied this set of stimulus-patterns a large number of times). In this manner, all responses made in a situation are successively associated with and then dissociated from those stimuli—all responses except one: the last response in a situation. It remains associated; for after it, no further response can be made with those stimuli present, and so no new responses can be cued to them. Therefore, the last response before termination of any stimulus-pattern will be the only one whose learned association with

those stimuli is preserved, and hence it will be the response elicited by them upon their next presentation.

(*c*) It is difficult of course to achieve clarity of communication or thinking if a variety of meanings exist for the same term. When working with Guthrie's theory, this difficulty is increased by the fact that the most common connotations of "recency" are those of Brown's term. Thus one finds himself confusing in his thinking and observations what the animal did last (connotations of Brown's meaning) with what the animal last did *in the particular stimulus situation* with which one is concerned.

(*d*) Probably partly because of an early linkage of frequency and recency as factors in learning (viz. Brown, Watson, Thorndike), there is a tendency toward considering the two together (cf. Peterson-1922, Reed-1927, Tolman-1934, Ruch-1941, McGeoch-1942). As a result, with elimination of frequency as inadequate or inconsistent with experimental findings (cf. Cuff-1929, Thorndike-1927 and 1932, Yoshioka-1928 and 1930), recency sometimes also has been automatically rejected, whether or not the data have any clear connection with it.[8]

(*e*) Finally, theoretical arguments (cf. that of Wilson, 1924, and others) have strongly indicated the invalidity of recency with Watson's rationale or the Brownian meanings, and experimental studies have suggested that "recency" in *some* senses is of little or no importance (cf. Peterson-1917 and 1922, Jersild-1929, Warden and Cummings-1929, Yoshioka-1930, Thorndike-1932). Through semantic difficulties, such works have been cited as evidence against the validity of *all* principles of "recency," although the various arguments and experiments may be relevant to "recency" in one sense only.

In view of the five points above, it seems advisable to introduce an unambiguous descriptive term for at least one of these principles of recency. "Postremity" (from the Latin adverb *postremo,* superlative of *last*) has been suggested, and it is the term which will be used in the present paper when referring to Guthrie's postulate, reserving the term "recency" for the more traditional principles.

It may be wondered why Postulate 1 is not alone sufficient, and why the "principle of postremity" was included. An answer to these questions is this:

Though Postulate 1 is consistent with Postulate 2, the former does not completely imply the latter. It is not Guthrie's view, but it is conceivable, that precisely the same stimulus could be the cue for not only one response

[8]This procedure is of course entirely legitimate for one particular principle of recency: namely, the principle *with Watson's rationale.*

or two compatible responses but for two (or more) incompatible responses; and this is a matter about which Postulate 1 says nothing.

Therefore to Postulate 1 must be added a second, either: (*a*) the same stimulus cannot be a CS for two incompatible responses (from this plus Postulate 1, we then could derive our present postulate concerning postremity), or else (*b*) if the same stimulus-pattern happens to be present while two incompatible responses are made, it will be cued to the postreme response only (which directly implies *"a"* above).

Of these logical alternatives, the latter was chosen as being clearer in its implications, placing the emphasis on a more important aspect of the problem, and being more directly applicable.

3. *Postulate 3: Principle of Response Probability*

The probability of any particular response's occurring (P_{R_Y}) at some specified time is an increasing monotonic function (x) of the proportion (N) of the stimuli present which are at that time cues for that response (S+). $P_{R_Y} = (N_{S+})^x$.

This principle often recurs in Guthrie's publications. For instance:

> "The 'strengthening' of an S-R connection with repetition may very possibly be the result of the enlistment of increasing numbers of stimuli as conditioners" (1930, p. 420).
>
> "A response conditioned upon two separate stimuli on separate occasions will be . . . more certain if the two conditioners are presented together. Two conditioners generally are more effective than one" (1935, p. 99).
>
> "Why should practice make the effect increasingly certain? Is it not possible that on successive practice periods more and more conditioners are enlisted, so that after twenty pairings there is a high probability that the cue will have enough support from the presence of these additional newly conditioned stimuli to be effective?" (1935, p. 100).[9, 10]

Similarly, in discussing why one often finds, as the Freudians have pointed out, better learning under conditions of excitement, Guthrie suggests that

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[9]As the reader conversant with these publications knows, other factors are also suggested to explain why repetition sometimes is efficacious in learning. For example, it may take many trials before one succeeds in once eliciting the response one wishes to establish as the CR to certain stimuli while those stimuli are present; it may be necessary to cue the response to many stimulus-patterns, not all of which can be present on one trial; and, the learning may be of such a nature that many sets of stimulus-patterns and response-patterns must be associated (as in learning a maze, other serial learning problems, or skills).

[10]See also 1933a, p. 134, lines 32-34; 1936, p. 111, lines 22-23; 1938a, p. 39 lines 29-31.

it may be due largely to the greater contraction of muscles during excitement, and that this "greater contraction stimulates new fields of proprioceptor sense organs. . . . These added stimuli may become conditioners of movement and hence explain the increased certainty of conditioning" (1935, p. 105. See also 1942a, p. 22.) This "explains the increased certainty" *if* one assumes Postulate 3, that the more cues there are for the response the more likely is the response.[11]

Before leaving this postulate, two of its implications should be clarified: (*a*) Is it necessary, according to the theory, to change more than half the stimulus-pattern to bring a change in response? (*b*) What are the conditions under which one will predict a change in response?

To the first question the answer is, "No." For any given trial, it is true, the most probable response theoretically is R_y if $P_{R_y} = 51\%$. But this does not mean that R_y should occur on *every* trial when $P_{R_y} = 51\%$. Rather according to the theory, the proportion of trials on which R_y will occur is equal to P_{R_y} (Postulate 3); and therefore, if $P_{R_y} = 51\%$ for each of 100 trials, R_y should occur on only 51 of those 100.

Postulate 3 states also that $P_{R_y} = (N_{S+})^x$. From this it follows directly that regardless of what value x may have, changing *any* part of the stimulus-pattern to non-cues for R_y will bring a change in response—in *some* instances (which is a part of the answer to Question 2 above). In other words, unless $N_{S+} = 1.00$, R_y will not invariably appear. Suppose the changes in N_{S+} are so slight that $P_{R_y} = 99\%$ for each one of some set of trials; out of 100 such trials, on the average one trial will be an instance in which R_y is *not* made.[12] But for a set of instances in which N_{S+} has a value such that $P_{R_y} = 80\%$, out of five of these, one will be an instance in which R_y is not made. It is obvious from this that when any part whatsoever of the stimulus-pattern is changed to *n* (non-cues for the response in question), there should be a change in response in at least some cases.[13]

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[11] A further cause suggested for better learning with excitement is that the "movements during excitement are more complete and vigorous than movements during unexcited states" (ibid.), so the response-to-be-learned is made more completely.

[12] By this theory, any one of the 100 is as apt to be the trial with the non R_y as any other trial.

[13] N_{S+} is the proportion of the total stimulus-pattern present on any specified trial which is composed of stimulus-patterns cued to the response in question. N_{S+} is *not* necessarily, therefore, the proportion of the total pattern which is the same as that present on some previous trial. For example, the value of N_{S+} may *change* even though the same pattern was present on two successive trials; on one trial N_{S+} may equal .60, but on the next trial (if R_+ occurred on the preceding trial) that same stimulus-pattern will now have an N of 1.00. Further, the value of N_{S+} may

To predict in *how many* cases, out of say 20, R_y will fail to occur, our knowing only N_{S+} will be insufficient; for the number of trials on which the response should appear is not directly proportional to the amount of the stimulus-pattern which is unchanged or, though changed, still composed of cues for the response in question, but is proportional rather to P_{R_y}. Hence, for this we need also to know the value of x. Consider these two cases in which N_{S+} for R_y equals .80: If $x = \frac{1}{2}$, $P_{R_y} = .89$ and R_y should fail to occur two times out of 20; but if $x = 2$, then $P_{R_y} = .64$ and R_y should fail to occur seven times out of 20.

Without knowing x, but assuming it remains constant for the set of cases being considered, we can make these predictions from the theory: (*a*) Introduction of any non-cues for R_y will result in a change in response in some cases. (*b*) the greater the change in the stimulus-pattern to non-cues for R_y (and hence the smaller the value of N_{S+}), the smaller will be the proportion of times on which R_y occurs. (*c*) A very small change in the stimulus-pattern can result in a substantial number of shifts from R_y to some other response. For instance, when one changes to Category *n* even 10 per cent of the total stimulus-pattern, in 5 per cent of such cases (if $x = \frac{1}{2}$) or in 19 per cent of such cases (if $x = 2$) some response other than R_y will occur.

4. *Postulate 4: Principle of Dynamic Situations*

The stimulus-pattern of a situation is not static but from time to time is modified, due to such changes as result from the subject's making a response, accumulation of fatigue products, visceral changes and other internal processes of the subject, introduction of controlled or uncontrolled variations in the stimuli present.

This postulate stresses that changes in stimulus-pattern go on virtually continuously, and emphasizes certain factors of theoretical importance which will bring about such changes (viz., the fact that there always will be a change in the stimuli as a result of making a response, since any response results in the introduction of new proprioceptive stimuli as well as in other internal modifications perhaps and results also in a change in the external stimulus-patterns acting on the subject). For a few of the places where this matter is stated explicitly or else assumed in Guthrie's discussions, one may consult the following references: 1935, p. 10; 1937a, p. 527, lines 13-22;

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remain the *same* from one trial S_- to another, although the stimulus-pattern has been changed; this would be the case if, for example, a certain proportion of S_+ stimuli were dropped but the same proportion of other S_- stimuli were added from one trial to the next, or if non-S_- stimuli were dropped and other non-S_- stimuli replaced them.

1938a, p. 39; 1942a, p. 31, last 2 paragraphs, and p. 32, paragraphs 2 and 3, as well as pp. 39-43; 1946c, p. 40, lines 24-27. This completes the present set of postulates, and we turn to the definitions.

C. Definitions

As most of these reflect to a considerable extent the conventional usage, no complete glossary of terms will be presented. The meaning of a few, however, differs somewhat from other accepted definitions; and since these differences constitute a unique and fundamental part of the theory, they are given below.

1. *Stimulus* (*S*) to an individual: Any change in physical energy or chemical state activating a receptor of some specified individual, thus setting up an afferent impulse to the CNS, and eventually an efferent impulse which elicits some response. It is clear that by this definition not all physical forces are stimuli; nor are energies which may be stimuli to an individual under some circumstances *always* stimuli to that individual. Physical forces must be in the Life Space of the individual to be stimuli for that individual.[14]

2. *Cue* (for a response): Any unconditioned or previously conditioned stimulus-pattern for the response in question.

Indirect cue (for some *R*): A stimulus-pattern which is a cue for that response indirectly, by being a cue for an R which leads to the creation of *S*'s which in turn are cues for the *R* in question. E.g., in an *S-R* chain such as this: S_1-R_1—S_2-R_2—S_3-R_3—S_4 . . . S_n-R_n, each *R* brings into existence other stimuli, these stimuli are cues for other responses, and all stimuli of that chain are indirect cues for R_n (except S_n which is a direct cue for R_n).

3. *Response* (*R*): The contraction of any group of muscles or the secretion of any gland or glands.[15] It will be noticed that gross *movement* is not necessary in order that something may be classed as a response. If many muscles are contracted (possibly antagonistics), this *is* a response even though the animal just "sits still." In part, it is this usage which led Guthrie to speak of "the response of not responding," although by that phrase he implies also any response other than that particular one in which the observer is most interested.

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[14] A bar, for example, does not furnish any stimulus-patterns to an animal on a "trial" when the animal is sitting in a somewhat distant corner with its back to the bar. Nor do curtain rods furnish any stimuli to a baby in another part of the room, looking somewhere else. Number of presentations of stimuli (as others view this) would not necessarily equal number of presentations of stimuli by this definition, for, what constitutes presentation of *S*'s-to-experimenter does not necessarily constitute *S*'s-to-subject.

[15] Logically, of course, a group may contain any number of members, including one.

4. *Conditioned response* (*CR*) to some *S*: Any response different from that which the *S* originally elicited through the effects of inherited structure and maturation alone.

5. *Indirect conditioned response* to a stimulus-pattern (e.g., S_1); Any response in an *S-R* chain such as S_1-R_1—S_2-R_2—S_3 . . ., other than R_1 which is the direct *CR* to S_1.

6. *Postreme response*: The last response made to a particular stimulus-pattern. (If R_1 was the last response to accompany Stimulus-Patterns 1-2-3, and R_2 was the last to accompany Stimulus-Patterns 4-5, there are two postreme responses for the situation of Stimulus-Patterns 1-2-3-4-5, R_1 and R_2, until some response occurs to this combination; then that response is the postreme response for the whole pattern and all parts of it.)

7. *Incompatible responses*: Two or more responses which cannot be made at the same time, either because of reciprocal innervation of the muscles involved or because of the same muscles' being used in two different ways in the two responses. Obviously, complex responses may be either partially or wholly incompatible.)

8. *Learning*: Any change in response to a situation which is the result of past responses to the same or similar situations and is not nullified to any degree by a period during which neither that nor any similar situation is presented.

This definition excludes fatigue and its effects. It also excludes phenomena which might be classified as learning by one who accepts a theory that effects of learning may partially disappear over a period of time, even when none of the cues has been present during the interim—a theory, in other words, that forgetting can occur in spite of there having been no chance for extinction through the occurrence of the *S-R* without subsequent reinforcement, and no chance either for counter-conditioning through the occurrence of some of the conditioned stimuli in conjunction with responses incompatible with the learned response in question. This restricted principle of disuse is not however one Guthrie holds, so the definition above excludes no phenomena he would consider "learning."

It includes all phenomena he does consider "learning." Some of these, it is true, would not be included under that rubric by other psychologists who, following the tradition of Hobhouse (1901), Thorndike (1911) and Lloyd Morgan (1930), delimit learning to changes which are an improvement or achievement in accordance with their plans. On this point Guthrie differs. His view is that learning has occurred not only when the animal eventually makes the "correct" response after having made "incorrect" responses, but also when he comes to make an "incorrect" response when he previously

made either correct responses or some other error to a similar stimulus-pattern. *"Learning" includes changes in behavior which are not necessarily a betterment* (cf., 1936, pp. 111-113; 1937a, p. 526, lines 1-3, and p. 528, lines 13-19; 1942a, p. 58, lines 11-12; 1942b, p. 105, lines 34-37 and p. 106, lines 1-7; 1946b, p. 286, lines 1-12 of col. 2).

Some of the considerations which lead to rejecting the classical definition are epitomized in the following passages:

> "This identification of learning with the attainment of a good result is all very well for common sense, but for a scientific understanding of human behavior it will not serve. And the reason that it will not serve is that in the same manner and in the same ways that human beings acquire skills and capacities, they also acquire faults and awkwardnesses and even lose capacities which they once possessed. Since virtues and skills are acquired in the same way that faults and awkwardnesses are acquired, it seems unreasonable to limit the meaning of the word learning to achievement. . . . We have deserted the methods of empirical science if we assume that all learning is good, that every action has its goal" (1935, p. 5).
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> "It is what gets done that is of practical importance. . . . But to use . . . goal attainment, success, as the essential criterion of learning, and to turn our search for facts to the observation of success and the conditions under which it is attained is analogous to . . . the definition by the physicist of work in terms of useful work or valuable work. . . . We must understand the processes through which behavior is *changed* for better or for worse" (1946a, p. 5).

D. Some Further Theoretical Implications

In this section are presented certain theorems flowing from the preceding postulates and definitions. In essence, each of these theorems states: When the conditions herein specified exist, then, if the theory is sound, this effect should result. The material in parentheses accompanying every statement in the theorem derivation gives the bases from which that particular statement logically follows.

The question has been raised as to how an animal can ever learn if Guthrie's theory is valid. The various steps in the derivation of Theorem I are an answer to this.

The statement of Theorem I gives the conditions under which a specified stimulus-pattern will come to elicit a response which was not elicited at some previous time by that particular pattern. That these are the *sufficient* conditions is demonstrated in Theorem I; that they are *necessary* conditions is demonstrated in Theorems II, III, and IV. In other words, if a sequence of events has all characteristics stated in *a, b,* and *c* of Theorem I, a new

response subsequently will be evoked by the same stimulus-pattern; if, on the other hand, the sequence of events has the characteristics stated in Theorem II or III or IV, no new response will come to be evoked by the specified stimulus-pattern.[16]

Theorem I: After a stimulus-pattern has been temporarily modified by (*a*) the addition of other stimuli which (*b*) result in a new response being made while (*c*) the original stimulus-pattern still is present, on its next presentation the original pattern will evoke a response it did not evoke before the preceding events occurred.

Symbols:[17]

Let R_1 = The response-pattern elicited by stimulus-pattern I at time *A*

R_2 = Any specified response-pattern not elicited at time *A* and different from (but not necessarily incompatible with) R_1

S_I = $S_1 + S_2 + S_3 + \ldots S_n$ = the stimulus-pattern present at time *A*

S_{II} = $S_I + S'$

S' = Any unconditioned or previously conditioned stimulus-pattern for R_2 which, even when presented with S_I at a time all stimuli of S_I are cues for R_1, evokes R_2

S_x = Any stimulus-pattern not included in S_I which does *not* evoke R_2 when added to S_I

A = Any time previous to *B*, when S_I is presented

B = The time when S_{II} is first presented subsequent to time *A*

C = Any time after time *B* when *S* is next presented

Deduction:

1) At time *A*, S_I elicits R_1 and does not elicit R_2. (Definition 1 and given.)[18]
2) At time *B*, S_{II} ($S_I + S'$) is presented and R_2 occurs. (Given.)
3) Immediately after time *B*, the stimuli of S_{II} are cues for R_2. (Step 2 postulate 1 a.)
4) Immediately after time *B*, the stimuli of S_I *without* S' have become cues for R_2. (Step 3.)
5) At time *C*, S_I is next presented. (Given.)
6) Between time *B*, and time *C*, S_I accompanies no response because not present. (Step 5.)
7) So at time *C*, S_I must be cues for R_2. Steps 4 and 6, Postulate 2b.)

[16]As stated, these first four theorems are concerned primarily with the conditions under which the *same* stimulus-patterns will come to evoke a response different from that which it formerly elicited. It is obvious that another way in which a different response may be evoked is by having a different stimulus-pattern present on that test trial. These are the two fundamental causes, and the conditions essential, for an animal's not always doing the same thing.

[17]Symbols are merely a mode of abbreviated expression and in defining them one should make no assumptions nor specify any conditions not given in the statement of the theorem, postulates, or definitions.

[18]"Given" indicates that the accompanying statement follows directly from one or more of the conditions specified in the statement of the theorem.

8) At time *C*, S_I will evoke R_2. (Steps 5 and 7, Postulate 3.)
9) Thus, the organism now (time *C*) makes a new response to S_I which formerly (time *A*) he did not make to that stimulus-pattern. (Steps 8 and 1.)
10) Hence, after a stimulus-pattern has been temporarily modified by (*a*) the addition of other stimuli which (*b*) result in a new response being made while (*c*) the original stimulus-pattern still is present, on its next presentation the original pattern will evoke a response it did not evoke before the preceding events occurred. (Steps 2 and 9.)

Theorems II, III, and *IV:* If additional stimulus-patterns are not presented (II) or if they do not evoke a different response (III) or if the specified stimulus-pattern is not still present (IV), the original specified pattern will continue to evoke only that response it formerly elicited.

Theorem II: Stated above.

Symbols: Same as before, except
Let *B* = A time after time *A* when S_I (with no additional stimuli) is next presented

Deduction:
1) At time *A*, S_I elicits R_1 (and are cues for R_1), but not R_2. (Given, Postulate 1a.)
2) At time *B*, S_I is re-presented with no additional stimuli. (Given.)
3) At time *B*, R_2 will not be evoked. (Step 2, Step 1 and Postulate 3.)
4) Therefore, at time *B*, S_I has not accompanied R_2. (Step 3.)
5) And the stimuli of S_I have not become cues for R_2. (Step 4, Step 1 and Postulate 1b.)
6) So the stimuli of S_I remain cues for R_1. (Steps 1 and 5, Postulate 2b.)
7) At time *C*, S_I is again presented. (Given.)
8) At time *C*, S_I will evoke R_1. (Steps 6 and 7, Postulate 3.)
9) At time *C*, S_I will not evoke R_2. (Step 5, Postulate 3.)
10) Hence, if (with the specified stimulus-pattern) additional stimulus-patterns are not presented, that specified pattern will continue to elicit on its subsequent presentations only the response it formerly elicited. (Steps 2, 1 and 8, 9.)

Theorem III: Even when additional stimulus-patterns are presented with a specified stimulus-pattern, if they do not evoke a new response, the original specified stimulus-pattern will continue to evoke only the response it elicited before the stimulus-pattern had been temporarily modified.

Symbols: Same as before, except
Let *B* = Any time subsequent to *A* at which S_I is re-presented with the addition of S_x

Deduction: Same as for Theorem II except the following steps should be substituted for the ones of corresponding number in Theorem II.

2) At time *B*, S_I is changed by adding S_x and the combination is presented. (Given.)

10) Hence, even when additional stimulus-patterns are presented with a specified stimulus-pattern, if this change does not result in a response different from that previously made to the original specified pattern, that pattern will continue to evoke (time *C*) only the response it formerly elicited (at time *A*) before the introduction of the change. (Steps 2, 1 and 8, 9.)

Theorem IV: If the specified stimulus-pattern is not still present when a new response is made, that pattern will continue to evoke only the response which it elicited previous to the change.

Symbols: Same as before, except

Let *B* = The time at which S′ is presented but S_I is not present

Deduction:

1) At time *A*, S_I elicits R_1. (Given.)

2) At time *B*, S′ is presented and R_2 is made; but S_I is not present. (Given.)

3) Therefore, S_I does not accompany R_2 at time *B*. (Step 2.)

4) So immediately after time *B*, S_I will not have become cues for R_2 (Step 3, Postulate 1b.)

5) And the stimuli of S_I remain cues for R_1. (Steps 1 and 3, Postulate 2b.)

6) S_I is next presented at time *C*. (Given.)

7) At time *C*, R_1 will be evoked by S_I. (Steps 5 and 6, Postulate 3.)

8) At time *C*, R_2 will not be evoked by S_I. (Steps 4 and 6, Postulate 3.)

9) At time *C*, S_I elicits the same response, and only that response, which it elicited before the change in stimulus-pattern. (Steps 1 and 7, 8.)

10) Hence, even when a change is made in stimulus-pattern so that a new response is evoked, if the original specified stimulus-pattern is not present at that time, the original pattern will continue to evoke on its presentation only the response it elicited previous to these events. (Steps 2, 9.)

The preceding theorems specify the condition under which an animal comes to make *new* responses to the same stimulus-pattern. However, under those conditions, that stimulus-pattern not only will come to elicit a new response but *may continue to elicit the old response as well.*

The conditions under which a specified stimulus-pattern will cease to elicit its old response are given in the theorem following; i.e., this theorem gives the necessary and sufficient conditions for extinction to occur.

Theorem V: A stimulus-pattern which now elicits a particular response will cease eliciting that response *when and only when* the stimulus-pattern subsequently (*a*) has been present while (*b*) some additional stimulus-pattern is presented which (*c*) elicits a new response incompatible with the old response.

Symbols: Same as before with this addition

Let R_3 = Any response not only different from but incompatible with R_1

Deduction:

1) At time *A*, S_I evokes R_1. (Given.)
2) At time *A*, R_1 is cued to S_I. (Step 1, Postulate 1.
3) S_I will cease being cues for R_1 when and only when S_I subsequently has accompanied an incompatible response, R_3. (Step 2, Postulate 2a and 2b.)
4) Therefore, S_I will cease to evoke R_1 when and only when S_I subsequently has accompanied R_3. (Step 3, Postulate 3.)
5) S_I does not evoke R_3 at time *A*. (Step 1, definition of "incompatible response"—Definition 7.)
6) S_I will never evoke R_3 unless Conditions *a*, *b*, and *c* have been fulfilled. (Step 5, Theorems II, III, IV.)
7) S_I will evoke R_3 when Conditions *a*, *b*, and *c* have been fulfilled. (Step 5, Theorem I.)
8) Therefore, S_I will come to evoke R_3 when and only when Conditions *a*, *b*, and *c* have been fulfilled. (Steps 6, 7.)
9) So S_I will cease to elicit R_1 when and only when Conditions *a*, *b*, and *c* have been fulfilled. (Steps 4 and 8.)
10) Hence, a stimulus-pattern which now elicits a particular response will cease eliciting that response when and only when it subsequently (*a*) has been present while (*b*) some additional stimulus-pattern is presented which (*c*) elicits a new response incompatible with the old response. (Step 9.)

For the remaining theorems, three additional definitions are needed, the symbols used in these definitions being those listed for Theorem VI.

9) *Alternation:* R_X occurring on the trial following a trial on which R_i occurred; or R_i occurring on the trial after one on which R_X occurred.

10) *Stable situation:* A set of stimulus-patterns on successive trials having the following characteristics—(*a*) all stimuli that are present on Trial *X* are present on all succeeding trials, (*b*) none of the stimuli present on Trial *X* is present between trials, (*c*) none absent from Trial *X* is added on succeeding trials.

11) *Relatively more unstable situation:* Compare to some other series of trials, a set having the following characteristics (*a*) a smaller proportion of those stimuli present on the various trials, ones which were present on a preceding trial when R_X was made, (*b*) a larger proportion of the stimuli present on the trials, either ones which were present last between trials, or else ones which were not present on any previous trial when R_X was made and are largely non-cues for R_X.

Theorem VI: For any given individual in a situation which is completely stable at least after the trial on which the new *CR* first is made, the new *CR* after once occurring will consistently occur, regardless of the past frequency with which that stimulus-pattern may have accompanied some other response or responses, i.e., P_{R_X} will jump from 0% to 100%.

Symbols:

Let R_X = The response E is interested in establishing as the *CR* to the experimental stimulus-patterns
R_i = Any response incompatible with R_X
X = The trial on which R_X first occurs
S_X = The stimulus-patterns present on Trial *X*

Deduction: For any given individual

1) On trial S, R_X occurs for the first time. (Given.)
2) Therefore, immediately after Trial *X*, all stimulus-patterns of S_X have become full-strength cues for R_X, regardless of how frequently they have been associated with some other response. (Steps 1, Postulates 1a and 2a.)
3) And immediately after trial X, all stimulus-patterns of S_X (which may have been cues for R_i) cease being cues for R_i. (Step 1, Postulate 2a.)
4) Between trial X and trial X + 1 (and between any other succeeding trials), none of S_X is present. (Given.)
5) So between trials, none of S_X can become a cue for R_i. (Step 4, Step 3, and Postulate 1b.)
6) Therefore, at the time that trial X + 1 is given, all stimulus-patterns of S_X will be cues for R_X. (Step 2, Steps 3, 5, and Postulate 2b.)
7) On trial X + 1, S_X and only S_X is presented. (Given.)
8) So on trial X + 1, $P_{R_X} = 100\%$. (Steps 6 and 7, Postulate 3.)
9) Therefore on trial X + 1, S_X will elicit R_X. (Steps 7 and 8, Postulate 3.)
10) Immediately after X + 1 (or any other trial on which R_X occurs), all stimuli of S_X are cues for R_X. (Step 9, Postulate 1a.)
11) Between trials X + 1 and X + 2 (and any other trials), no stimuli of S_X can cease being cues for R_X. (Steps 4 and 5.)
12) On trial X + 2 (and all succeeding trials), S_X and only S_X is presented. (Given.)
13) Therefore when trial X + 2 is given, 100% of the stimulus-pattern is composed of cues for R_X. (Steps 10, 11, 12.)
14) Therefore, on trial X + 2, R_X will be evoked. (Step 13, Postulate 3.)
15) Similarly on all succeeding trials, R_X will be evoked. (Step 14, and Steps 10, 11, 12, and Postulate 3.)
16) Hence, for any given individual in a situation which is completely stable at least after the trial on which the new *CR* is first made,

the new *CR* after once appearing will consistently do so, regardless of the past frequency with which some other response may have accompanied that stimulus-pattern. (Steps 9, 14, 15.)

Theorem VII: Assuming (1) not more than one-half the total stimulus-pattern after the first *CR* is consistently composed of patterns which are not cues for the response in question (R_X), and (2) that the response between trials is R_i, in any specified number of trials after Trial *X* there will be, on the average, more alternations for a group of subjects in a relatively less stable situation than a group in any relatively more stable situation.

Symbols: Same as for Theorem VI, with these additions

Let L = Any situation relatively less stable than Situation *M*

M = Any situation relatively more stable than Situation *L*

Deduction:

1) Compared to *M*, on the trials for *L* a smaller proportion of stimulus-patterns are ones that were present when R_X occurred. (Given, and Definition 11.)
2) Therefore, the total pattern of *L* contains from this source a smaller proportion of cues for R_X than that of *M*. (Step 1, Postulate 1.)
3) Compared to *M*, a larger proportion of the stimulus-patterns presented during the trials in *L* are patterns which were last present between trials. (Given, Definition 11.)
4) Stimulus-patterns present between trials are, at the beginning of the next trial, cues for R_i and no longer cues for R_X. (Given — Assumption 2, Postulate 2a.)
5) Therefore, *L* has a larger proportion of cues for R_i than does *M*. (Steps 3 and 4, Postulate 2a.)
6) Compared to *M*, in *L* a larger proportion of stimulus-patterns present on various trials are patterns not present before, and most of these are not cues for R_X. (Given, and Definition 11.)
7) So, in general, *L* has a lower P_{R_X} than has *M*. (Steps 2, 5, and 6, Postulate 3.)
8) For each individual, the occurrence of *R* is a function of P_{R_X} (Postulate 3.)
9) Therefore, in any specified number of trials, more of the responses will be R_i for a group of subjects in situation *L* than for one in *M*. (Steps 7 and 8.)
10) P_{R_X} for both *L* and *M* is above fifty per cent for the majority of trials after Trial *X*. (Given — Assumption 1.)
11) So for subjects in either *L* or *M*, on the average more than one-half the responses after Trial *X* will be R_X. (Step 10.)
12) Therefore, in any specified number of trials after Trial *X*, more alternations will occur on the average for the group in Situation *L* than that in Situation *M*. (Steps 9 and 11.)
13) Hence, assuming not more than one-half the total stimulus-pattern is consistently composed (after the first *CR*) of patterns which are

not cues for the response in question (R_X), and that the last response between trials is R_i, in any specified number of trials after the first *CR* there will be, on the average, more alternations for a group of subjects in a relatively less stable situation than a group in any relatively more stable situation. (Step 12.)

Theorem VIII: In any specified number of trials following the first R_X, on the average there will be longer consecutive series of R_X's for a group under relatively more stable stimulus conditions than for a group under relatively less stable conditions.

Symbols: Same as for Theorem VII.

Deduction:

1) On Trial *X*, R_X occurs. (Given.)
2) to 7) Same as Steps 1 through 6 for Theorem VII.
8) Therefore on trial X + 1 and subsequent trials, P_{R_X} is higher on the average for subjects in Situation *M* than for the group in Situation *L*. (Steps 2 through 7.)
9) The higher is the value of P_{R_X}, the more likely is R_X. (Postulate 3.)
10) So for each trial after *X*, R_X is more likely for subjects in Situation *M* than for ones in *L*. (Steps 8 and 9.)
11) Therefore, unless the number of trials following *X* is less in *M* than in *L*, there will be on the average longer consecutive series of R_X in *M* than in *L*. (Step 10.)
12) Hence, in any specified number of trials, following R_X, on the average there will be longer consecutive series of R_X's for a group under relatively more stable stimulus conditions than for a group under relatively less stable conditions. (Step 11.)

E. Summary

For the advancement of our science, and to meet other theoretical and pragmatic considerations, we must have precise formalization of as many theories (conceivably correct syntheses of information) as possible.

An effort was made to systematize and clarify one theory of learning (that of Guthrie) by more explicit formulation of the postulates and definitions apparently constituting the basis of that theory, presentation of certain aspects wherein this theory differs from others, and discussion of some questions concerning the theory. It is entirely possible these postulates will need to be revised in light of further observation and almost certain they will need to be supplemented by others.

Also, eight theorems and their derivation from the present system were presented. These show some implications of the theory, give an answer to various questions, and are open to experimental tests. (In fact, the writer is preparing a report of an experiment testing them.) They are but a few of the theorems which may be deduced from the postulates as they stand.

It was suggested that "postremity" be used as the descriptive term for the Guthrian postulate and rationale stressing the importance of the response made last to a specified stimulus-pattern. This suggestion was made in view of the variety of meanings and rationales for "recency," the nature of various connotations of the term, a rather confusing linkage of recency and frequency, and the results of this state of affairs.

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