*Psychological Review*
1960, Vol. 67, No. 6, 380–400

# BLIND VARIATION AND SELECTIVE RETENTION IN CREATIVE THOUGHT AS IN OTHER KNOWLEDGE PROCESSES[1]

DONALD T. CAMPBELL

*Northwestern University*

This paper proposes to examine creative thought within the framework of a comparative psychology of knowledge processes, and in particular with regard to one theme recurrent in most knowledge processes. This theme may be expressed as follows:

1. A blind-variation-and-selective-retention process is fundamental to all inductive achievements, to all genuine increases in knowledge, to all increases in fit of system to environment.
2. The many processes which shortcut a more full blind-variation-and-selective-retention process are in themselves inductive achievements, containing wisdom about the environment achieved originally by blind variation and selective retention.
3. In addition, such shortcut processes contain in their own operation a blind-variation-and-selective-retention process at some level, substituting for overt locomotor exploration or the life-and-death winnowing of organic evolution.

Between a modern experimental physicist and some virus-type ancestor there has been a tremendous gain in knowledge[2] about the environment. In bulk, this has represented cumulated inductive achievements, stage by stage expansions of knowledge beyond what could have been deductively derived from what had been previously known. It has represented repeated "breakouts" from the limits of available wisdom, for if such expansions had represented only wise anticipations, they would have been exploiting full or partial knowledge already achieved. Instead,

[1] A partially overlapping version of this paper was presented at the Inter-Disciplinary Conference on Self-Organizing Systems, sponsored by the Office of Naval Research and the Armour Research Foundation of the Illinois Institute of Technology, Chicago, May 5–6, 1959. The proceedings of the conference are to be published by Pergamon Press under the title *Self-Organizing Systems*. The author is indebted to Carl P. Duncan for contributing to the development of many of the points involved.

[2] This extended usage of "knowledge" is a part of an effort to put "the problem of knowledge" into a behavioristic framework which takes full cognizance of man's status as a biological product of an evolutionary development from a highly limited background, with no "direct" dispensations of knowledge being added at any point in the family tree. The bibliographical citation of the several sources converging on this approach to the problem of knowledge, and the discussion of its relation to traditional philosophical issues and to the strategy of science are presented elsewhere (Campbell, 1959). Suffice it to say here that the position limits one to "an epistemology of the other one." The "primitives" of knowledge can not be sought in "raw feels" or in "phenomenal givens," or in any "incorrigible" elements. While man's conscious knowledge processes are recognized as more complex and subtle than those of lower organisms, they are not taken as more fundamental or primitive. In this perspective, any process providing a stored program for organismic adaptation in external environments is included as a knowledge process, and any gain in the adequacy of such a program is regarded as a gain in knowledge. If the reader prefers, he can understand the paper adequately regarding the term "knowledge" as metaphorical when applied to the lower levels in the developmental hierarchy. But since the problem of knowledge has resisted any generally accepted solution when defined in terms of the conscious contents of the philosopher himself, little seems lost and possibly something gained by thus extending the range of processes considered.

real gains must have been the products of explorations going beyond the limits of foresight or prescience, and in this sense blind. In the instances of such real gains, the successful explorations were in origin as blind as those which failed. The difference between the successful and unsuccessful was due to the nature of the environment encountered, representing discovered wisdom about that environment.

The general model for such inductive gains is that underlying both trial-and-error problem solving and natural selection in evolution, the analogy between which has been noted by several persons (e.g., Ashby, 1952; Baldwin, 1900; Pringle, 1951). Three conditions are necessary: a mechanism for introducing variation, a consistent selection process, and a mechanism for preserving and reproducing the selected variations. In what follows we shall look for these three ingredients at a variety of levels. But first a comment on the use of the word "blind" rather than the more usual "random." It seems likely that Ashby (1952) unnecessarily limited the generality of his mechanism in Homeostat by an effort to fully represent all of the modern connotations of random. Equiprobability is not needed, and is definitely lacking in the mutations which lay the variation base for organic evolution. Statistical independence between one variation and the next, while frequently desirable, can also be spared: in particular, for the generalizations essayed here, certain processes involving systematic sweep scanning are recognized as blind, insofar as variations are produced without prior knowledge of which ones, if any, will furnish a selectworthy encounter. An essential connotation of blind is that the variations emitted be independent of the environmental conditions of the occasion of their occurrence. A second important connotation is that the occurrence of trials individually be uncorrelated with the solution, in that specific correct trials are no more likely to occur at any one point in a series of trials than another, nor than specific incorrect trials. (Insofar as observation shows this not to be so, the system is making use of already achieved knowledge, perhaps of a general sort. The prepotent responses of an animal in a new puzzle box toward the apparent openings may thus represent prior general knowledge, transferred from previous learning or inherited as a product of the mutation and selective survival process.) A third essential connotation of blind is rejection of the notion that a variation subsequent to an incorrect trial is a "correction" of the previous trial or makes use of the direction of error of the previous one. (Insofar as mechanisms do seem to operate in this fashion, there must be operating a substitute process carrying on the blind search at another level, feedback circuits selecting "partially" adequate variations, providing information to the effect that "you're getting warm," etc.)

## REVIEW OF THE THEME IN LOWER KNOWLEDGE PROCESSES

In this perspective, the epistemologically most fundamental knowledge processes are embodied in those several inventions making possible organic evolution. At the already advanced level of cellular life, this is a "learning" on the part of the species by the blind variation and selective survival of mutant individuals. In terms of the three requirements, variation is provided by the mutations, selection by the somewhat consistent or "knowable" vagaries of the environment, and preservation and duplication by the complex and rigid order of chromosome mitosis. Bisexuality, heterozygosity, and meiotic cell division represent a secondary invention increasing the efficiency of the process through increasing the range of variation and the rate of readjustment to novel environments. The selection and preservation processes remain the same. The ubiquity of bisexuality, its several independent inventions, and the multifarious elaboration of the theme, all speak to its tremendous usefulness.

The higher evolutionary developments shift a part of the locus of adaptation away from a trial and error of whole organisms or gene pools, over to processes occurring within the single organism. Such processes are numerous, each being not only a device for obtaining knowledge, but also representing general wisdom about environmental contingencies already achieved through organic evolution, making possible more efficient achievement of detailed local knowledge. One of the most primitive of these is exploratory locomotion, described in the protozoa by Jennings (1906) and accepted as a model for Homeostat by Ashby (1952). Forward locomotion persists until blocked, at which point direction of locomotion is varied blindly until unblocked forward locomotion is again possible. The external physical environment is the selection agency, the preservation of discovery is embodied in the perseveration of the unblocked forward movement. At this level, the species has "discovered" that the environment is discontinuous, consisting of penetrable regions and impenetrable ones, and that impenetrability is to some extent a stable characteristic—it has discovered that when blocked it is a better strategy to try to go around than to wait until one can move through.

Insofar as individual organisms without distance receptors (such as paramecia and earthworms) can learn through contiguity, the species has already achieved the more general knowledge that there is some event-contingency stability in the environment. That is, in the degree to which individual learning is useful, there has been the species-level discovery of slower transformation processes on the part of relevant segments of the environment than of the organism. In addition, whereas the ultimate selection is life or death in encounters with the external environment, by the evolutionary stage at which learning is possible, much of this once-external criterion has been internalized. Crude environmental contingencies with low selection ratios are now represented as pleasures or pains, or as reinforcers more generally. The selection becomes much more sharp, but the contact with the environmental realities less direct.

The presence of a fundamental trial-and-error process in individual learning needs no elaboration or defense. Suffice it to say that recognition of such a process is found in all learning theories which make any pretense of completeness, including at least three of Gestalt inspiration (Campbell, 1956a). While higher vertebrate (and higher cephalopod) learning makes far more use of the short circuiting of overt trial and error by vision than is allowed for by the usual learning theory (Campbell, 1956b), for convenience here the multiplication of levels will be avoided by treating trial-and-error learning as a single process level.

The next and most striking class of discoveries are those centering around echo-location and vision. Woodworth (1921) has emphasized the achievement of a percept from the ingredients of sensation through a series of "trial-and-error perceptions." Thurstone (1924) has interpreted perception as a trial and error of potential locomotions placed in a hierarchy of trial-and-error processes including both overt trial and error and ideational trial and error, in a book containing many anticipations of cybernetic concepts. Pumphrey (1950) interprets the primitive sense receptor of the fishes called the "lateral-line organ" as a crude echo-location device, making use of the reflected pulses of the fish's own swimming. Griffin (1958) has documented in detail the use by bats and cave birds of sonic and supersonic vocalizations selectively reflected by obstacles of the environment. Kellogg (1958) has made a similar case for the porpoise. Here is a powerful substitute for blind locomotor exploration. (See Simon, 1957, p. 264, for an estimate of such gains.) In echo location a wave pulse is emitted blindly in all directions. The obstacles of the environment selectively reflect the pulse from certain of these directions, and thus provide a feedback which is substitutable for that which would have been received had the animal locomoted in those directions. Radar guidance systems employ an analogous substitution of a blindly scanning electromagnetic wave pulse, in economical substitution for a blind scanning of the same environment of potential locomotions by full ship or projectile movements.

Visual perception seems interpretable as a substitute search process of similar order (Campbell, 1956b). The full analogy is weakened by the absence of an emitting process on the part of the organism. Instead, advantage is taken of diffuse electromagnetic waves made available from external sources. Consider first a pseudoeye consisting of but a single photoreceptor cell. (Such a device has been distributed for use by the blind in which a photocell output is transformed into a sound of variable pitch.) With such a device, blind scanning as in a radar system is essential. Brightness contours can be located and fixated by continual crossing, as in the "hunting" process in a mechanical servosystem, or as in the vocal pitch control in which a steady note is "held" only by a continuous search oscillation (Deutsch & Clarkson, 1959). To conceive of such an "eye" as a blind searching device substituting for a more costly blind locomotion in the explored directions is not difficult. The eyes of insects and vertebrates and the higher cephalopods differ from such a device by having multiple photocells, making possible selective reflection from objects in multiple directions at once. Each receptor cell can be conceived of as exploring the possibilities of locomotion in a given direction, the retina collectively thus exploring the possibilities of locomotion in a wide segment of potential directions for locomotion. Except as the eye is aimed by other sources of knowledge, these possibilities have been made "blindly" available without prescience or insight. For the "blindness" of an eyeless animal there has been substituted a process so efficient that we use it naively as a model for direct, unmediated knowing. But the process is still one of blind search and selective retention, in the sense employed in this paper.

Vision is a very complex and marvelous mechanism, and the brief presentation here does not do justice even to the random search components involved. Hebb (1949) has well documented the active search of eye movements, correcting the model of the inactive fixed-focus eye which is implicit in both Gestalt psychology and conditioning theory. Riggs (Riggs, Armington, & Ratliff, 1954) and Ditchburn (1955) have documented the essential role of the continuous low amplitude scanning provided by "physiological nystagmus" or "fixation tremor." Platt (1958) has provided a brilliant analysis of the role of a blind "rubbing" process, his "lens-grinding" model, for the achievement of visual acuity and spatial representation in a visual system containing unaddressed elements. These and other considerations convince the present writer that although vision represents the strongest challenge to the generality a blind-variation-and-selective-retention aspect to all knowledge processes, it is not in fact an exception. These brief comments have not fully justified this conclusion, however.

Taking these echo location and visual exploratory processes collectively, several general aspects can be noted: all exploit a specific and limited coincidence, i.e., that objects impenetrable by organismic locomotion also are opaque to, or reflect, certain wave forms in the acoustical frequencies and in the bands of electromagnetic waves of the visual and radar spectra. It is this coincidence, unpredictable upon the basis of the prior knowledge available to the more primitive organisms, which makes possible such marvelously efficient shortcuts. Thus while phenomenologically vision is more direct than other knowledge processes, it is seen in this perspective as an indirect, substitute process. As in all substitute knowledge processes, the effectiveness is limited by the accuracy of the coding process, i.e., the translation terms between one level and another. Such coding is never exhaustive (Platt, 1956). It always involves abstraction, and along with this some fringe imperfection and proneness to systematic error. It must finally be checked out and corrected by overt locomotion. Its efficacy is limited by the *relevance* of the coding to the more fundamental level of behavior for which it is a substitute. This relevance was itself initially tested out by a blind-variation-and-selective-retention process at the level of organic evolution or early childhood learning. (Species differ in this regard.) The phenomenal directness of vision tempts us to make vision prototypic for knowing at all levels, and leads to that chronic belief in the potential existence of direct and "insightful" mental processes, a belief which it is one purpose of this paper to deny.

## CREATIVE THOUGHT

Creative thought provides the next level knowledge process for the present discussion. At this level there is a *substitute* exploration of a *substitute* representation of the environment, the "solution" being selected from the multifarious exploratory thought trials according to a criterion which is in itself *substituting* for an external state of affairs. Insofar as the three substitutions are accurate, the solutions when put into overt locomotion are adaptive, leading to intelligent behavior which lacks overt blind floundering, and is thus a knowledge process. To include this process in the general plan of blind-variation-and-selective-retention, it must be emphasized that insofar as thought achieves innovation, the internal emitting of thought trials one by one is blind, lacking prescience or foresight. The process *as a whole* of course provides "foresight" for the overt level of behavior, once the process has blindly stumbled into a thought trial that "fits" the selection criterion, accompanied by the "something clicked," "Eureka," or "aha-erlebnis" that usually marks the successful termination of the process.

Today, we find the blind-variation-and-selective-retention model most plausibly applied at the levels of organic evolution and trial-and-error learning of animals, and least palatable as a description of creative thinking. Historically, however, the phrase "trial and error" was first used to describe thinking, by Alexander Bain as early as 1855, two years before Darwin's publication of the doctrine of natural selection. Not only for historical interest, but also to further develop the psychology of creativity, the following quotations from him (Bain, 1874) are provided:

> Possessing thus the material of the construction and a clear sense of the fitness or unfitness of each new tentative, the operator proceeds to ply the third requisite of constructiveness—trial and error— . . . to attain the desired result. . . . The number of trials necessary to arrive at a new construction is commonly so great that without something of an affection or fascination for the subject one grows weary of the task. This is the *emotional* condition of originality of mind in any department (p. 593).
>
> In the process of Deduction . . . the same constructive process has often to be introduced. The mind being prepared beforehand with the principles most likely for the purpose . . . incubates in patient thought over the problem, trying and rejecting, until at last the proper elements come together in the view, and fall into their places in a fitting combination (p. 594).
>
> With reference to originality in all departments, whether science, practice, or fine art, there is a point of character that deserves notice. . . . I mean an Active turn, or a profuseness of energy, put forth in trials of all kinds on the chance of making lucky hits . . . Nothing less than a fanaticism of experimentation could have given birth to some of our grandest practical combinations. The great discovery of Daguerre, for example, could not have been regularly worked out by any systematic and orderly research; there was no way but to stumble upon it. . . . The discovery is unaccountable, until we learn that the author . . . got deeply involved in trials and operations far removed from the beaten paths of inquiry (p. 595).

In 1881 Paul Souriau presented a still more preponderant emphasis on the factor of chance as the sole source of true innovation. He asserts again and again that "le principe de l'invention est le hasard." In the main, he presents his argument through illustration and through the elimination of rival hypotheses about the inventive process, including deduction, induction, and "la methode." A positive explanation of the process is hard to find. This sample will illustrate his approach:

> A problem is posed for which we must invent a solution. We know the conditions to be met by the sought idea; but we do not know what series of ideas will lead us there. In other words, we know how the series of our thoughts must end, but not how it should begin. In this case it is evident that there is no way to begin except at random. Our mind takes up the first path that it finds open before it, perceives that it is a false route, retraces its steps and takes another direction. Perhaps it will arrive immediately at the sought idea, perhaps it will arrive very belatedly: it is entirely impossible to know in advance. In these conditions we are reduced to dependence upon chance.
>
> In the case just analysed we supposed that we had to solve a problem already stated for us. But how was the problem-statement itself found? It is said that a question well posed is half answered. If so, then true invention consists in the posing of questions. There is something mechanical, so to speak, in the art of finding solutions. The truly original mind is that which discovers problems. But here again, it does no good to speak of method, since method is the application of already existing discoveries. The discovery of a new problem can therefore only be fortuitous. Thus we see the role of logic diminish and that of chance increase as we approach closer to true invention. Chance is the first principle of invention: it is what has produced method, nourished it, and made it fertile. Method can only analyse the ideas which come to it from elsewhere, drawing out their consequences and exhausting their contents. Left to itself method soon becomes sterile. Methodological minds cannot help having a feeling of disdain for adventurous minds which affirm before proving and believe before knowing. But they must recognize that without such audacity, no progress would be possible. The mind is not able to revise itself upon its own

foundations. New ideas cannot have prototypes: their appearance can only be attributed to chance (pp. 17–18).

Souriau has not only the notion of chance combinations, but also the concept of their being produced in large numbers which are generally worthless and from which only the rare ones fitting a goal or criterion are selected. These two widely separated quotations illustrate this:

By a kind of artificial selection, we can in addition substantially perfect our thought and make it more and more logical. Of all of the ideas which present themselves to our mind, we note only those which have some value and can be utilized in reasoning. For every single idea of a judicious and reasonable nature which offers itself to us, what hosts of frivilous, bizarre, and absurd ideas cross our mind. Those persons who, upon considering the marvelous results at which knowledge has arrived, cannot imagine that the human mind could achieve this by a simple fumbling, do not bear in mind the great number of scholars working at the same time on the same problem, and how much time even the smallest discovery costs them. Even genius has need of patience. It is after hours and years of meditation that the sought-after idea presents itself to the inventor. He does not succeed without going astray many times; and if he thinks himself to have succeeded without effort, it is only because the joy of having succeeded has made him forget all the fatigues, all of the false leads, all of the agonies, with which he has paid for his success (p. 43).

. . . If his memory is strong enough to retain all of the amassed details, he evokes them in turn with such rapidity that they seem to appear simultaneously; he groups them by chance in all the possible ways; his ideas, thus shaken up and agitated in his mind, form numerous unstable aggregates which destroy themselves, and finish up by stopping on the most simple and solid combination (pp. 114–115).

The phrase "artificial selection" is reminiscent of Darwin's writings, although Souriau makes no mention of the selective-survival model of evolution, (nor does he cite the ideas of any other person whatsoever).[8] Note how similar the final quotation is to Ashby's (1952) phrasing of the inevitable self-elimination of unstable combinations:

Just as, in the species, the truism that the dead cannot breed implies that there is a fundamental tendency for the successful to replace the unsuccessful, so in the nervous system does the truism that the unstable tends to destroy itself imply that there is a fundamental tendency for the stable to replace the unstable (p. vi).

Ernst Mach was another great 19th century thinker about thinking who emphasized this model. We today remember him most as a psychologist-physicist-philosopher who contributed to the present day positivistic recognition of the hypothetic character of our constructions of the world and who first made explicit the empirical presumptions involved in the physicist's assumption of an Euclidian space. But when, at the age of 57 in 1895, he was called back to his alma mater the University of Vienna to assume a newly created position of Professor of the History and Theory of Inductive Science, he chose a quite different theme for his inaugural address. His title was "on the part played by accident in invention and discovery." The occasion indicates the importance he gave to the message, and indeed,

[8] Souriau's presentation is in general quite modern in spirit, although associationistic in a way some would find dated, and vigorously deterministic in a way now undermined by subatomic physics, although not necessarily so for the problems of which he treats. He comments wisely on many topics not covered here, including simultaneous independent invention and the Zeitgeist, the social conditions of creativity and invention, the dissonance created by discrepant opinions of others, the congruence of free will and determinism, and both the conflict and interdependency between erudition and innovation. His attacks on both deduction and induction are reminiscent of Peirce's later critiques.

his paper is a neglected classic in the psychology of knowledge processes. These quotations (Mach, 1896) further reinforce the model of creative thought being presented:

> The disclosure of new provinces of facts before unknown, can only be brought about by accidental circumstances . . . (p. 168).
>
> In such [other] cases it is a psychical accident to which the person owes his discovery—a discovery which is here made "deductively" by means of mental copies of the world, instead of experimentally (p. 171).
>
> After the repeated survey of a field has afforded opportunity for the interposition of advantageous accidents, has rendered all the traits that suit with the word or the dominant thought more vivid, and has gradually relegated to the background all things that are inappropriate, making their future appearance impossible; then from the teeming, swelling host of fancies which a free and high-flown imagination calls forth, suddenly that particular form arises to the light which harmonizes perfectly with the ruling idea, mood, or design. Then it is that that which has resulted slowly as the result of a gradual selection, appears as if it were the outcome of a deliberate act of creation. Thus are to be explained the statements of Newton, Mozart, Richard Wagner, and others, when they say that thoughts, melodies, and harmonies had poured in upon them, and that they had simply retained the right ones (p. 174).

Poincaré (1908, 1913) in his famous essay on mathematical invention presents a point of view which is also judged to be in agreement. He first gives an example in imagery: "One evening, contrary to my custom, I drank black coffee and could not sleep. Ideas rose in crowds; I felt them collide until pairs interlocked, so to speak, making a stable combination" (Poincaré, 1913, p. 387). Poincaré feels that it is rare for this blind permuting process to rise into conscious awareness, and that as a rule only the successful selected alternatives enter consciousness. Because of the relevance of Poincaré's comments; because Hadamard (1945) has cited him in opposition to the accidentalist position while he is read here as favoring the selective-retention version of it; and because of all of the sources cited he would most generally be respected as truly creative (in the field of mathematics) these longish excerpts (Poincaré, 1913) are read into the record:

> It is certain that the combinations which present themselves to the mind in a sort of sudden illumination, after an unconscious working somewhat prolonged, are generally useful and fertile combinations, which seem the result of a first impression. Does it follow that the subliminal self, having divined by a delicate intuition that these combinations would be useful, has formed only these, or has it rather formed many others which were lacking in interest and have remained unconscious?
>
> In this . . . way of looking at it, all the combinations would be formed in consequence of the automatism of the subliminal self, but only the interesting ones would break into the domain of consciousness. *And this is still very mysterious.* What is the cause that, among the thousand products of our unconscious activity, some are called to pass the threshold, while others remain below? Is it a simple chance which confers this privilege? Evidently not; among all the stimuli of our senses, for example, only the most intense fix our attention, unless it has been drawn to them by other causes. More generally the privileged unconscious phenomena, those susceptible of becoming conscious, are those which, directly or indirectly, affect most profoundly our emotional sensibility (p. 391).
>
> . . . we reach the following conclusion: The useful combinations are precisely the most beautiful, I mean those best able to charm this special sensibility that all mathematicians know, but of which the profane are so ignorant as often to be tempted to smile at it.
>
> What happens then? Among the great numbers of combinations blindly formed by the subliminal self, almost all are without interest and without utility; but just for that reason they are also without effect upon the esthetic sensibility. Consciousness will never know them; only certain ones are harmonious, and, consequently, at once useful and beautiful. They will be capable of

touching this special sensibility of the geometer of which I have just spoken, and which, once aroused, will call our attention to them, and thus give them occasion to become conscious.

This is only a hypothesis, and yet here is an observation which may confirm it: when a sudden illumination seizes upon the mind of the mathematician, it usually happens that it does not deceive him, but it also sometimes happens, as I have said, that it does not stand the test of verification; well, we almost always notice that this false idea, had it been true, would have gratified our natural feeling for mathematical elegance.

Thus it is this special esthetic sensibility which plays the role of the delicate sieve of which I spoke, and that sufficiently explains why the one lacking it will never be a real creator.

Yet all the difficulties have not disappeared. The conscious self is narrowly limited, and as for the subliminal self we know not its limitations, and this is why we are not too reluctant in supposing that it has been able in a short time to make more different combinations than the whole life of a conscious being could encompass. Yet these limitations exist. Is it likely that it is able to form all the possible combinations, whose number would frighten the imagination? Nevertheless that would seem necessary, because if it produces only a small part of these combinations, and if it makes them at random, there would be small chance that the *good*, the one we should choose, would be found among them.

Perhaps we ought to seek the explanation in that preliminary period of conscious work which always precedes all fruitful unconscious labor. Permit me a rough comparison. Figure the future elements of our combinations as something like the hooked atoms of Epicurus. During the complete repose of the mind, these atoms are motionless, they are, so to speak, hooked to the wall; so this complete rest may be indefinitely prolonged without the atoms meeting, and consequently without any combination between them.

On the other hand, during a period of apparent rest and unconscious work, certain of them are detached from the wall and put in motion. They flash in every direction through the space (I was about say the room) where they are enclosed, as would, for example, a swarm of gnats or, if you prefer a more learned comparison, like the molecules of gas in the kinematic theory of gases. Then their mutual impacts may produce new combinations.

What is the role of the preliminary conscious work? It is evidently to mobilize certain of these atoms, to unhook them from the wall and put them in swing. We think we have done no good, because we have moved these elements a thousand different ways in seeking to assemble them, and have found no satisfactory aggregate. But, after this shaking up imposed upon them by our will, these atoms do not return to their primitive rest. They freely continue their dance.

Now, our will did not choose them at random; it pursued a perfectly determined aim. The mobilized atoms are therefore not any atoms whatsoever; they are those from which we might reasonably expect the desired solution. Then the mobilized atoms undergo impacts which make them enter into combinations among themselves or with other atoms at rest which they struck against in their course. Again I beg pardon, my comparison is very rough, but I scarcely know how otherwise to make my thought understood.

However it may be, the only combinations that have a chance of forming are those where at least one of the elements is one of those atoms freely chosen by our will. Now, it is evidently among these that is found what I call the *good combination.* Perhaps this is a way of lessening the paradoxical in the original hypothesis.

Another observation. It never happens that the unconscious work gives us the result of a somewhat long calculation *all made,* where we have only to apply fixed rules. We might think the wholly automatic subliminal self particularly apt for this sort of work, which is in a way exclusively mechanical. It seems that thinking in the evening upon the factors of a multiplication we might hope to find the product ready made upon our awakening, or again that an algebraic calculation, for example a verification, would be made unconsciously. Nothing of the sort, as observation proves. All one may hope from these inspirations, fruits of unconscious work, is a point of departure for such calculations. As for the calculations themselves, they must be made in the second period of conscious work, that which follows the inspiration, that in which one verifies the results of this inspiration and deduces their consequences. The rules of these calculations are strict and complicated. They require discipline, attention, will, and therefore consciousness. In the subliminal self, on the contrary, reigns what I should call liberty, if we might give this name to the simple absence of discipline and to the disorder born of chance. Only, this disorder itself permits unexpected combinations (pp. 392–394).

In addition to these pioneers there of course have been numerous others who in some manner have made a substitute trial and error in a modeled or mnemonic environment an important aspect of their description of thinking. In rough chronology these include Baldwin (1906), Pillsbury (1910), Rignano (1923), Woodworth (1921), Woodworth & Schlosberg (1954), Thurstone (1924), Tolman (1926), Hull (1930), Muenzinger (1938), Miller and Dollard (1941), Craik (1943), Boring (1950), Humphrey (1951), Mowrer (1954), Sluckin (1954), and many others.

## OBJECTIONS TO THE MODEL

### *The Gestalt Protest*

The trial-and-error theme in learning was of course one part of the syndrome of ideas against which Gestalt psychology eloquently protested. In spite of this, there is judged to be no inherent conflict between the perspectives of this paper and the Gestalt position. To make this interpretation, it is necessary to regard neither traditional associationism nor Gestalt psychology as discrete integrated wholes, but instead to regard each as congeries of which the parts may be separately accepted or rejected.

The Gestaltists are judged to have validly rejected Thorndike's (1898) description of animal problem solving as solely a matter of overt locomotor trial and error. As this writer (Campbell, 1956b) has argued previously, recognizing vision as a substitute trial-and-error process leads to the expectation that some locomotor problems will be solved by this means, obviating overt trial and error. Even more so does the model for thought. To the present writer the Gestaltists were correct descriptively even though epistemologically the trial-and-error process remains fundamental to discovery. In Wertheimer's (1959) specific contrasts between insightful problem solving and blind trial and error, it is a *trial and error of overt manipulation* which is involved. Furthermore, as Humphrey (1951) and Woodworth and Schlosberg (1954) point out, the Gestalt descriptions of problem solving provide ample evidence of both fortuitous solutions and misleading "insights." The recurrent Gestaltist protest that even the errorful trials are "intelligent" and that the subsequent trials make use of what was learned through the error are taken here as equivalent to the statements that the problem solver had some valid general knowledge to begin with, and that before acting he employed the substitute trial and error of thought or vision.

The blind-variation-and-selective-retention model of thought joins the Gestaltists in protest against the picture of the learning organisms as a passive induction machine accumulating contingencies. Instead, an active generation and checking of thought-trials, hypotheses, or molar responses is envisaged. The model at the level of thought places essential importance upon internalized selective criteria against which the thought trials are checked. Poincaré's (1913) esthetic criteria and the Gestalt qualities of wholeness, symmetry, organized structure, and the like can be regarded as built-in selective criteria completely compatible with the model. Pringle (1951) for example, has proposed a selective-retention model of central nervous system action in which systematic temporal patterns provide the selective criteria in a resonance process.

Nor does the model here presented specify the nature of the thought trials employed. There must often be a trial and error among possible general principles, or among rational abstractions, or field reorganizations, or re-centerings. Both the blind variation and selective survival model, and Gestalt theory emphasize the advantage of breaking out of old ruts, and the disadvantages of set and rote drill (Boring, 1950; Dunker, 1945; Katona, 1940; Luchins, 1942; Wertheimer, 1959). Furthermore, the encountering in thought of an idea which fits can be accompanied at the phenomenal level by a joyful "ahaerlebnis" or a Gestalt experience of "closure," and at the overt performance level by a sudden and stable improvement signifying "insight." There is no essential disagreement here. Nor is the trial-and-error model without phenomenological support. Note the highly similar testimony from the disparate historical citations provided above, especially in the imagery of multitudinous, loosened, agitated, teeming, colliding, and interlocking ideas.

This is not to say that a Gestalt psychologist would be happy with the blind-variation-and-selective-retention description of thought processes. Nor are all aspects of the Gestalt syndrome here accepted. While "insight" is accepted as a phenomenal counterpart of the successful completion of a perhaps unconscious blind-variation cycle, its status as an explanatory concept is rejected, especially as it connotes "direct" ways of knowing. Furthermore, when publicized as a part of an ideology of creativity, it can reduce creativity through giving students a feeling that they lack an important gift possessed by some others, a feeling which inhibits creative effort and increases dependence upon authority. Polya (1945, 1954) has described such an inhibiting tradition in the teaching of mathematics.

### *Individual Differences and Genius*

Another prevalent orientation antithetical in spirit to the blind-variation-and-selective-retention model may be called the "mystique of the creative genius and the creative act." This is related to our deeply rooted tendency toward causal perception (e.g., Heider, 1944), a tendency to see marvelous achievements rooted in equally marvelous antecedents. It takes the form of the "fallacy of accident" and of "*post hoc ergo propter hoc.*" Let a dozen equally brilliant men each propose differing guesses about the unknown in an area of total ignorance, and let the guess of one man prove correct. From the blind-variation-and-selective-survival model this matching of guess and environment would provide us with new knowledge about the environment but would tell us nothing about the greater genius of the one man—he just happened to be standing where lightning struck. In such a case, however, we would ordinarily be tempted to look for a subtle and special talent on the part of this lucky man. However, for the genuinely unanticipatable creative act, our "awe" and "wonder" should be directed outward, at the external world thus revealed, rather than directed toward the antecedents of the discovery. Just as we do not impute special "foresight" to a successful mutant allele over an unsuccessful one, so in many cases of discovery, we should *not* expect marvelous consequents to have had equally marvelous antecedents. Similarly, in comparing the problem-solving efforts of any one person; from the selective survival model it will be futile, in the instance of a genuinely innovative achievement, to look for special antecedent conditions not obtaining for blind-alley efforts: just insofar as there has been a genuine gain in knowledge, the difference between a hit and a miss lies in the selective conditions thus newly encountered, not in talent differences in the generation of the trials.

This is not to deny individual differences in creative intellect. Indeed, the blind-variation-and-selective-retention model of creative thought predicts such talent differences along all of the parameters of the process. This is to emphasize, however, that explanations in terms of special antecedents will very often be irrelevant, and that the causal-interpretative biases of our minds make us prone to such over-interpretations, to *post-hoc-ergo-proper-hoc* interpretations, deifying the creative genius to whom we impute a capacity for direct insight instead of mental flounderings and blind-alley entrances of the kind we are aware typify our own thought processes. Ernst Mach (1896) notes our nostalgia for the directly-knowing genius: "To our humiliation we learn that even the greatest men are born more for life than for science in the extent to which even they are indebted to accident" (p. 175).

What are the ways in which thinkers might be expected to differ, according to the trial-and-error model? First, they may differ in the accuracy and detail of their representations of the external world, of possible locomotions in it or manipulations of its elements, and of the selective criteria. Differences in this accuracy of representation correspond to differences in degree of information and intelligence. Second, thinkers can differ in the number and range of variations in thought trials produced. The more numerous and the more varied such trials, the greater the chance of success. Bain has emphasized the role of fanaticism or extreme dedication in producing large volumes of such explorations. Bain, Souriau, Mach, and Poincaré have all emphasized the role of advance preparation in assembling the elements whose blind permutation and combination make possible a wide range of trials. Many observers have emphasized the role of set and familiarity in reducing the range of variations, and have recommended ways of reducing trial-to-trial stereotypy, as by abandoning the problem for awhile, going on to other things. Devices abound which are designed to increase the likelihood that all permutations be considered and are used by most of us, as in going through the alphabet in finding rhymes or puzzle words. There are no doubt age differences in the rapidity and uninhibited range of thought-trial production. The sociology of knowledge makes an important contribution here: persons who have been uprooted from traditional cultures, or who have been thoroughly exposed to two or more cultures, seem to have the advantage in the range of hypotheses they are apt to consider, and through this means, in the frequency of creative innovation. Thorstein Veblen (1919) has espoused such a theory in his essay on the intellectual preeminence of Jews, as has Robert Park (1928) in writing of the role of "the marginal man" in cultural innovation. (See also Seeman, 1956.) And more generally, it is the principle of variation which leads us to expect among innovators those of personal eccentricity and bizarre behavior. We can also see in this principle the value of those laboratories whose social atmospheres allow wide ranging exploration with great tolerance for blind alley entrances.

The value of wide ranging variation in thought trials is of course vitiated if there is not the precise application of a selective criterion which weeds out the overwhelming bulk of inadequate trials. This editing talent undoubtedly differs widely from person to person, as Poincaré (1908, 1913) has emphasized. With regard to selection criteria, one further point should be made. Much of creative thought is opportunistic in the sense of having a wide number of selective criteria available at all times, against which the thought trials are judged. The more creative thinker may be able to keep in mind more such criteria, and therefore increase his likelihood of achieving a serendipitous (Cannon, 1945; Merton, 1949) advance on a problem tangential to his initial main line of endeavor (e.g., Barber & Fox, 1958). Further areas of individual differences lie in the competence of the retention, cumulation, and transmisison of the encountered solutions.

It need not be expected that these dimensions of talent all go together. In organic evolution, the variation process of mutation and the preservation of gains through genetic rigidity are at odds, with an increase in either being at the expense of the other, and with some degree of compromise being optimum. Just so we might expect that a very pure measure of innovative range in thought and a very pure measure of rote memory might be even negatively correlated, as Saugstad (1952) seems to have found, and similarly for innovative range and selective precision. Such considerations suggest complementary combinations of talent in creative teams, although the uninhibited idea-man and the compulsive edit-and-record type are notoriously incompatible office mates.

Notice regarding the individual differences thus described that while they do make creative innovation much more likely on the part of some individuals than others, they do not place the joys of creative innovation beyond the reach of the less gifted. Indeed, looking at large populations of thinkers, the principles make it likely that many important contributions will come from the relatively untalented, undiligent, and uneducated, even though on an average contribution per capita basis, they will contribute much less, points which Souriau (1881) has noted. The intricacy of the tradition to which innovation is being added of course places limitations in this regard.

### *The Enormous Domain of Possible Thought-Trials to be Searched*

A final type of objection to the blind-variation-and-selective-retention model of thought needs to be considered. This objection is to the effect that the domain of possible thought trials is so large that the solution of a given problem would take an impossibly long time were a search of all possibilities to be involved, either through a systematic scanning of all possibilities where these are enumerable, or through a random sampling of the universe of possibilities. Time and trial estimates thus based can be overwhelming, as Kurt Lasswitz's story "The Universal Library" (1958) dramatically illustrates. Other parodies of our model occur in literature as far back as Swift's portrait of the Academy of Lagado in *Gulliver's Travels* (1941, pp. 166–169). (Ley, 1958, traces such ideas back to Lully, ca. 1200.) Newell, Shaw, and Simon (1958a, 1958b) refer in this vein to what they call the "British Museum Algorithm," i.e., the possibility of a group of trained chimpanzees typing at random producing by chance in the course of a million years all of the books in the British Museum. Such parodies seem effectively to reject the blind-variation-and-selective-retention model through a *reductio ad absurdum*. Needless to say, such a rejection is not accepted in the present paper. As a matter of fact, it is judged to be in the same class as parallel objections to the theory of natural selection in evolution. Similar features in these two instances make the accidentalist interpretation more acceptable.

1. Neither in organic evolution nor in thought are all problems solved, nor all possible excellent solutions achieved. There is no guarantee of omniscience. The knowledge we do encounter is achieved against terrific odds. (Those advocating heuristically-programed problem-solving computers are careful not to guarantee solutions, and this modesty should be extended to all models of creative thought.)

2. The tremendous number of nonproductive thought trials on the part of the total intellectual community must not be underestimated. Think of what a small proportion of thought becomes conscious, and of conscious thought what a small proportion gets uttered, what a still smaller fragment gets published, and what a small proportion of what is published is used by the next intellectual generation. There is a tremendous wastefulness, slowness, and rarity of achievement.

3. In biological evolution and in thought, the number of variations explored is greatly reduced by having *selective criteria imposed at every step.* Thus mutant variations on nonadaptive variations of the previous generation are never tested—even though many wonderful combinations may be missed therefore. Some of the "heuristics" currently employed in logic and chess playing machines (Newell, Shaw, & Simon, 1958a, 1958b) have the similar effect of evaluating all next-possible moves in terms of immediate criteria, and then of exploring further variations upon only those stems passing the screening of each prior stage. It is this strategy of cumulating selected outcomes from a blind variation, and then exploring further blind variations only for this highly select stem, that, as R. A. Fisher has pointed out (e.g., 1954, p. 91) makes the improbable inevitable in organic evolution. This strategy is unavoidable for organic evolution, but can obviously be relaxed in thought processes and in machine problem solving. However, the Pandora's box of permutations opened up by such relaxation can be used to infer that, in general, thought trials are selected or rejected within one or two removes of the established base from which they start. In constructing our "universal library" we stop work on any volume as soon as it is clear that it is gibberish.

4. When we make estimates of the number of permutations which would have to be culled to obtain a given outcome, we often assume that problem solving was undertaken with that one fixed goal in mind. This overlooks the opportunistic, serendipitous course of organic evolution and of much of creative thinking. The likelihood of a productive thought increases with the wider variety of reasons one has for judging a given outcome "interesting." To neglect this opportunistic multipurposedness gives one a poor base for estimating the probability of encountering the one outcome hit upon and recorded. Thus when Newell, Shaw, and Simon's "Logic Theorist" (1958a, 1958b) sets out to prove the 60-odd theorems in a given chapter of *Principia Mathematica,* it may face a more formidable task than did Whitehead and Russell in generating them, if, except for the dozen classic theorems reproduced, Whitehead and Russell were otherwise free to record every deduction they encountered which seemed "interesting"

or "nontrivial." Wigglesworth (1955) has noted this strategy on the part of "pure" scientists, in commenting on the relationship between pure and applied scientists in wartime:

> In the pure science to which they were accustomed, if they were unable to solve problem A they could turn to problem B, and while studying this with perhaps small prospect of success they might suddenly come across a clue to the solution of problem C (p. 34).

In presenting their case for adding "heuristics" to the program of the "Logic Theorist," Newell, Shaw, and Simon have emphasized the inadequacy of blind trial and error. So has Miller (1959) in advocating the heuristic of searching backward from the goal.[4] There is, however, no essential disagreement between their point of view and the one offered here. By adding heuristics mechanical thought processes have indeed been made more like those of human beings, both in adequacy and type of errors. Such innovations have obviated the protests of those such as Wisdom (1952) and Mays (1956) who, while conceding that machines could choose good moves at chess or solve logic problems, have found the machines failing to imitate life just in their orderly inspection of all possibilities. Newell, Shaw, and Simon recognize that a machine which would develop its own heuristics would have to do so by a trial and error of heuristic principles, with no guarantee that any would work. They further recognize that possession of an effective heuristic represents already achieved general knowledge about the domain under search, and that adding to this general knowledge will be a blind search process. (The devices of learning and vision and of coding environmental possibilities for thought-search

[4] Miller (1959, pp. 244–246) is wrong in implying that the strategy of working backward from the goal eliminates the necessity of symbolic trial and error in creative thinking. His mistake comes from assuming that only one path leads into a goal or subgoal. In the spatial locomotion problems from which his concrete illustrations come, and for the logic problems used by Newell, Shaw, and Simon, the paths into any position are not singular, but are instead typically as numerous as paths leading out. A *pure* strategy of working from the goal back to the start would thus involve exploring just as many permutations as the pure strategy of exploring all paths from the start position. However, there is a useful strategy available to symbolic trial and error and not to overt trial and error, in working concurrently from both ends. This produces a dramatic advantage in the number of permutations generated, and a smaller but still substantial gain in the number of comparisons. In the instance suggested by Miller in which each locus branches into 4 alternatives and in which the start and goal turn out to lie 7 stages apart, either of the pure strategies would generate $4 + 4^2 + 4^3 + 4^4 + 4^5 + 4^6 + 4^7$ or 21,844 permutations (neglecting the probable achievement of success before exhausting the $4^7$ generation of alternatives). For the mixed approach, the junction would be encountered at the third stage away from each end, or when $2(4 + 4^2 + 4^3)$ or 168 alternatives had been examined. In the pure strategy, there would be 21,845 comparisons involved, that is, the start position and each subsequent alternative would be compared with the goal. In the mixed strategy, many more comparisons per alternative are required. Each permutation must be compared with each of the current and previous permutations on the other stem, which in this instance amounts to 7,225 comparisons. If the comparisons are regarded as equally costly as the generating and storing of alternatives, the savings of the mixed approach over either of the pure approaches would amount to approximately 1 to 6, a very handsome gain for any heuristic. This gain is larger as the number of branches at each stage increases. Advocacy of the heuristic of working backwards in what is essentially this mixed form is present in Polya (1945), Wisdom (1952), and Newell, Shaw, and Simon (1958a, 1958b). In none of these is it claimed that trial and error is eliminated, while all point to the reduction in trials which it can achieve.

all represent heuristics in this sense.) They might also agree that most heuristic devices will be limited to the specific domain of their discovery, and can only be extended to other domains on a trial basis. They would probably also agree that no problem solving process will be "direct." The disagreements I have with their excellent paper on the processes of creative thinking (Newell, Shaw, & Simon, 1958b) are thus minor matters of emphasis, but may be worth stating nonetheless, to further clarify the position here advocated. They say, for example:

> We have given enough estimates of the sizes of the spaces involved . . . to cast suspicion upon a theory of creativity which places its emphasis upon increase in trial and error (p. 63).

The blind-variation-and-selective-retention model unequivocally implies that *ceteris paribus,* the greater the heterogeneity and volume of trials the greater the chance of a productive innovation. Doubling the number of efforts very nearly doubles the chance of a hit, particularly when trials are a small part of the total domain and the repetitiousness among trials is low. But they too recognize unconventionality and no doubt numerosity as a necessary, if not a sufficient condition of creativity (1958b, p. 62). What they would validly stress, is the very frequent tactical advantage of a trial and error of general strategic principles over a trial and error involving no classificatory effort nor attempt to use clues, and, once such general heuristics have been discovered, the advantages of a hierarchized trial and error process. The advantage of such a strategy depends upon the ecology, of course, but we are in general justified in expecting solutions to be nonrandomly distributed, and to show significant contingencies with prior clues. Polya (1945, 1954) has, of course, been a major source of inspiration for all efforts to introduce heuristics into problem solving, and for him a trial and error approach is a heuristic of fundamental importance.

Another minor point of disagreement may be mentioned. In their efforts to consider how a "Logic Theorist" might be programed to learn a general heuristic from hindsight they propose that it keep a record of the outcomes of all past trials, successful and unsuccessful, in order to be able to scan its experience for general principles of strategy (1958b). Implementing this would put a tremendous strain upon memory storage, and would introduce a scanning process as time consuming as the original search process which produced the record. The strategy of organic evolution is to keep a record only of what works, even at the expense of repeating its errors. The general preponderance of wrong tries at every level, plus problems of memory glut and access, suggests a similar strategy for all knowledge processes. Heuristics can probably best be learned through a trial and error of heuristics, tried on new problem sets rather than old.

## STATUS AS A THEORY

At the level here developed, one might better speak of an "orientation to," or a "perspective on" creative thought processes, rather than a "theory of." At many points, this perspective merely points to problems, rather than taking that step toward theory of providing guesses at answers: e.g., for the processes here outlined to be possible, theory must not only provide several memory processes, but most importantly, must specify a possible mechanism for the trial-and-error search of these. From such specifications will come the subtlety of prediction characteristic of a developed theory.[5] While the perspective even in its very general state has some unequivocal empirical implications, the major advantage to it may be metaphysical, or at least metatheoretical. Like the theory of natural selection in organic evolution, it provides an understanding of marvelously purposive processes without the introduction of teleological metaphysics or of pseudocausal processes working backward in time.

Note that there are still ambiguities about the status *as theory* of the well established principle of organic evolution through natural selection, even though now buttressed with the detailed genetic model of the variation and retention processes. Scriven (1959) has called it an explanatory rather than a predictive theory. While the present writer feels that Scriven has somewhat undervalued the experimental studies of evolution with viruses, bacteria, and insects, and may have mistaken the past absence of experimental settings appropriate to testing the theory for an inherent attribute of the type of theory per se; he has called attention, nonetheless, to some serious problems. Even Sewall Wright (1960), whose statistical genetic theory of evolution has added subtle details to the overall description of the process, has commented in a similar vein:

> The theory is deterministic only in an exceedingly limited sense. It is essentially a theory of the conditions favorable for an ever continuing process that is essentially unpredictable in its details. There can be no formula for serendipity (p. 148).

The problems which a selective retention theory of creative thinking shares with that of evolution include the following:

1. The basic insight, so useful and so thrilling when first encountered, is close to being an analytic tautology rather than a synthetic description of process: if indeed variations occur which are differentially selected and propagated, then an evolutionary process toward better fit to any set of consistent selective criteria is inevitable.

2. For most applications of the selective retention model, the variation is taken as a descriptive given, as an unexplained part of the explanation. While other predictive theories likewise depend upon unexplained processes at a more molecular level, this instance may seem evasive at a particularly crucial point, and has indeed been taken as a denial of determinism or as a rival metaphysic of "spontaneous change" as presumptive as a teleological one. We are currently getting detailed deterministic explanations of the mutation of genes, but until something comparable is available to predict the generation of heterogeneous thought trials, this constitutes a weakness of the model.

3. The biological study of the evolution of any species takes the form of a post hoc reconstruction of a unique, "undetermined," historical process. The achievement of any general regularities must be probabilistic in the extreme. Studies starting from specific spectacular achievements in creative thought must be similar in nature.

4. The theory suffers from the multiplicity

[5] This paper does not attempt to review theories in this area. Citations to the important contributions of Pringle (1951) and Hebb (1949), do not begin to represent this literature. Note the special problem of a brain analogue to switching. Ashby's (1952) model and most computer memory search involves a spatial displacement of solids impossible in the brain, as in the stepping switch or the rotation of a magnetic memory drum. Computer memory search processes making use of timed pulses require a precision of timing dependent upon a stability of dimension presumably not available in the brain and usually if not always dependent upon a clock within which actual spatial displacement of solids takes place. It is for these reasons that Pringle's (1951) theory seems particularly promising, and one wonders why it has not been more used, or if not usable, more publicly refuted. See Pribram (1959) for a recent contribution to the problem of appropriate brain process models.

of possible mediations it posits. Where there are gaps in the historical knowledge, the theory makes available an embarrassing surfeit of possible reconstructions. In this, and in contrast to the successful theories of macrophysics, the theory is less self-disciplining, less specific in its predictions, more evasive of potential disconfirmation. This is perhaps the most important of Scriven's (1959) points, and one equally applicable to the theory of creative thinking.

5. In the usual applications, the environment is not described or describable prior to the organismic achievement of adaptation to that environment. Whereas the theory deals with an iterative process whereby an organism adapts to (achieves knowledge of) an independent environment, the evidences as to the organismic form and environmental parameters are often confounded, in that the same data series is used to infer both. While this is not so for laboratory studies of trial-and-error learning, it is particularly apt to be so for any study of truly great creative thinking in science. (See Campbell, 1959, p. 157 for epistemological citations to this problem.)

There is in addition, a serious problem which the blind-variation-and-selective-retention theory of creative thought faces which is not present in comparable degree in the modern theory of organic evolution. This is the unfavorable ratio of hypothesized unobservable processes to observable input-output variables. Note that even in its sketchy form here given, some 6 to 14 or more separately variable parameters are implied. These include: (*a*) A mnemonic representation of environment, varying perhaps in scope, accuracy, and fineness of detail; (*b*) A mnemonic search or thought-trial process, varying in the accuracy with which it represents potential overt exploration; (*c*) A thought-trial generating and changing process, varying in rate, heterogeneity, idiosyncrasy, and lack of repetitiousness among successive thought trials; (*d*) Selective criteria, varying in their number, accuracy of representation of environmental contingencies, and precision, sharpness, or selection ratio; (*e*) A preservation or propagation process, providing a retention for selected thought trials of a quite different order from the memory traces of the nonselected ones, varying perhaps in accuracy and accessibility; (*f*) A reality testing process in which the selected thought trials are checked out by overt locomotion in the external environment, varying perhaps in sensitivity to disconfirming feed-back.

This inventory of weaknesses does not, of course, represent argument in favor of rival theories of creative thought, which are judged to be still more amorphous, still less adequate. And as Duncan (1959) makes clear in reviewing the research literature on human problem solving, for all theories there is lacking a disciplined relation both to experimental undertakings and to findings. Even in its present form, however, the theory contains many empirical implications. Manipulation of any one of the 14 variables just listed should increase the number of creative products, providing the other variables can be held constant. Predictions of this order have been specified in the discussion of individual differences. Particularly characteristic are the unequivocal predictions regarding the volume and heterogeneity of thought trials. *Ceteris paribus,* a creative solution is more likely the longer a problem is worked upon, the more variable the thought trials, the more people working on the problem independently, the more heterogeneous these people, the less the time pressure, etc.

## SUMMARY

This paper has attempted to make the psychological and epistemological point that all processes leading to expansions of knowledge involve a blind-variation-and-selective-retention process. Processes, such as vision and

thought, substituting for an overt trial and error are of couse acknowledged. But each of these are interpreted as containing in its very workability wisdom about the environment obtained originally by the blind variation of mutation and natural selection. In addition, each contains a blind-variation-and-selective-retention process at its own level. Supporting the effort to interpret all knowledge processes in this light has been an emphasis upon the tremendous gain in knowledge in the course of evolution and history, a gain which can only be explained by a continual breakout from the bounds of what was already known, a breakout for which blind variation provides the only mechanism available.

The application of this perspective to the process of creative thought antedates its application to trial-and-error learning in animals and to organic evolution, and is illustrated through quotations from Bain, Souriau, Mach, and Poincaré. The model is not in disagreement with the bulk of the Gestalt description of problem solving, nor the work on heuristically programed problem-solving computers. However, there is an effort to root out a prevailing implicit belief in the possibility of "direct" or "insightful" creative thought processes.

## REFERENCES


ASHBY, W. R. *Design for a brain.* New York: Wiley, 1952.

BAIN, A. *The senses and the intellect.* (3rd ed.) New York: Appleton, 1874.

BALDWIN, J. M. *Mental development in the child and the race.* New York: Macmillan, 1900.

BALDWIN, J. M. *Thought and things, or genetic logic.* Vols. I-III. New York: Macmillan, 1906–1911.

BARBER, B., & FOX, R. C. The case of the floppy-eared rabbits: An instance of serendipity gained and serendipity lost. *Amer. J. Sociol.*, 1958, **64**, 128–136.

BORING, E. G. Great men and scientific progress. *Proc. Amer. Phil. Soc.*, 1950, **94**, 339–351.

CAMPBELL, D. T. Adaptive behavior from random response. *Behav. Sci.*, 1956, **1**, 105–110. (a)

CAMPBELL, D. T. Perception as substitute trial and error. *Psychol. Rev.*, 1956, **63**, 330–342. (b)

CAMPBELL, D. T. Methodological suggestions from a comparative psychology of knowledge processes. *Inquiry*, 1959, **2**, 152–182.

CANNON, W. B. *The way of an investigator.* New York: Norton, 1945.

CRAIK, K. J. W. *The nature of explanation.* Cambridge: Cambridge Univer. Press, 1943.

DEUTSCH, J. A., & CLARKSON, J. K. The nature of the vibrato and the control loop in singing. *Nature*, 1959, **183**, 167–168.

DITCHBURN, R. W. Eye-movement in relation to retinal action. *Optica Acta*, 1955, **1**, 171–176.

DUNCAN, C. P. Recent research on human problem solving. *Psychol. Bull.*, 1959, **56**, 397–429.

DUNKER, K. On problem-solving. *Psychol. Monogr.*, 1945, **58**(5, Whole No. 270).

FISHER, R. A. Retrospect of the criticism of the theory of natural selection. In J. Huxley, A. C. Hardy, & E. B. Ford (Eds.), *Evolution as a process.* London: Allen & Unwin, 1954.

GRIFFIN, D. R. *Listening in the dark.* New Haven: Yale Univer. Press, 1958.

HADAMARD, J. *The psychology of invention in the mathematical field.* Princeton: Princeton Univer. Press, 1945.

HEBB, D. O. *The organization of behavior.* New York: Wiley, 1949.

HEIDER, F. Social perception and phenomenal causality. *Psychol. Rev.*, 1944, **51**, 358–374.

HULL, C. L. Knowledge and purpose as habit mechanisms. *Psychol. Rev.*, 1930, **37**, 511–525.

HUMPHREY, G. *Thinking.* London: Methuen, 1951.

JENNINGS, H. S. *The behavior of the lower organisms.* New York: Columbia Univer. Press, 1906.

KATONA, G. *Organizing and memorizing.* New York: Columbia Univer. Press, 1940.

KELLOGG, W. N. Echo-ranging in the porpoise. *Science*, 1958, **128**, 982–988.

LASSWITZ, K. The universal library. (First published 1901) In C. Fadiman (Ed.), *Fantasia mathematica.* New York: Simon & Schuster, 1958.

LEY, W. Postscript to "The universal library." In C. Fadiman (Ed.), *Fantasia mathematica.* New York: Simon & Schuster, 1958. Pp. 244–247.

LUCHINS, A. Mechanization in problem solving: The effect of Einstellung. *Psychol. Monogr.,* 1942, **54**(6, Whole No. 248).

MACH, E. On the part played by accident in invention and discovery. *Monist,* 1896, **6**, 161–175.

MAYS, W. Cybernetic models and thought processes. *Proceedings of the First International Congress on Cybernetics, Namur.* Paris: Gauthier-Villard, 1956.

MERTON, R. K. *Social theory and social structure.* Glencoe, Ill.: Free Press, 1949.

MILLER, N. E. Liberalization of basic S-R concepts: Extensions to conflict behavior, motivation, and social learning. In S. Koch (Ed.), *Psychology: A study of a science.* Vol. 2. *General systematic formulations, learning, and special processes.* New York: McGraw-Hill, 1959.

MILLER, N. E., & DOLLARD, J. *Social learning and imitation.* New Haven: Yale Univer. Press, 1941.

MOWRER, O. H. Ego psychology, cybernetics, and learning theory. In *Kentucky symposium: Learning theory, personality theory, and clinical research.* New York: Wiley, 1954. Pp. 81–90.

MUENZINGER, K. F. Vicarious trial and error at a point of choice: I. A general survey of its relation to learning efficiency. *J. genet. Psychol.,* 1938, **53**, 75–86.

NEWELL, A., SHAW, J. C., & SIMON, H. A. Elements of a theory of human problem solving. *Psychol. Rev.,* 1958, **65**, 151–166. (a)

NEWELL, A., SHAW, J. C., & SIMON, H. A. *The process of creative thinking.* University of Colorado 1958 symposium on cognition. *Rand Corp. Rep.,* 1958, No. P-1320. (b)

PARK, R. E. Human migration and the marginal man. *Amer. J. Sociol.,* 1928, **33**, 881–893.

PILLSBURY, W. B. *The psychology of reasoning.* New York: Appleton, 1910.

PLATT, J. Amplification aspects of biological response and mental activity. *Amer. Scient.,* 1956, **44**, 181–197.

PLATT, J. Functional geometry and the determination of pattern in mosaic receptors. In H. P. Yockey, R. L. Platzman, & H. Quastler (Eds.), *Symposium on information theory in biology.* New York: Pergamon, 1958. Pp. 371–398.

POINCARÉ, H. L'invention mathematique. *Bull. Inst. Gen. Psychol.,* 1908, **8**, 175–187.

POINCARÉ, H. Mathematical creation. In H. Poincaré, *The foundations of science.* New York: Science Press, 1913.

POLYA, G. *How to solve it.* Princeton, N. J.: Princeton Univer. Press, 1945.

POLYA, G. *Mathematics and plausible reasoning.* Vol. I. *Induction and analogy in mathematics.* Vol. II. *Patterns of plausible inference.* Princeton, N. J.: Princeton Univer. Press, 1954.

PRIBRAM, K. H. On the neurology of thinking. *Behav. Sci.,* 1959, **4**, 265–287.

PRINGLE, J. W. S. On the parallel between learning and evolution. *Behaviour,* 1951, **3**, 175–215.

PUMPHREY, R. J. Hearing. In *Symposia of the Society for Experimental Biology.* IV. *Physiological mechanisms in animal behavior.* New York: Academic Press, 1950.

RIGGS, L. A., ARMINGTON, J. C., & RATLIFF, F. Motions of the retinal image during fixation. *J. Opt. Soc. Amer.,* 1954, **44**, 315–321.

RIGNANO, E. *Psychologie du raisonnement.* Paris: Alcan, 1920. (Reprinted: *The psychology of reasoning.* New York: Harcourt, Brace, 1923).

SAUGSTAD, P. Incidental memory and problem-solving. *Psychol. Rev.,* 1952, **59**, 221–226.

SCRIVEN, M. Explanation and prediction in evolutionary theory. *Science,* 1959, **130**, 477–482.

SEEMAN, M. Intellectual perspective and adjustment to minority status. *Soc. Probl.,* 1956, **3**, 142–153.

SIMON, H. A. *Models of man.* New York: Wiley, 1957.

SLUCKIN, W. *Minds and machines.* Harmondsworth: Penguin, 1954.

SOURIAU, P. *Theorie de l'invention.* Paris: Hachette, 1881.

SWIFT, J. *Gulliver's travels.* (Originally published 1726) Oxford: Blackwell, 1941.

THORNDIKE, E. L. Animal intelligence: An experimental study of the associative processes in animals. *Psychol. Rev. Monogr. Suppl.,* 1898, **2**(4, Whole No. 8).

THURSTONE, L. L. *The nature of intelligence.* New York: Harcourt, Brace, 1924.

TOLMAN, E. C. A behavioristic theory of ideas. *Psychol. Rev.,* 1926, **33**, 352–369.

VEBLEN, T. The intellectual preeminence of Jews in modern Europe. *Pol. sci. Quart.* 1919, **34**, 33–42.

WERTHEIMER, M. *Productive thinking.* New York: Harper, 1959.

WIGGLESWORTH, V. B. The contribution of pure science to applied biology. *Ann. appl. Biol.,* 1955, **42**, 34–44.

WISDOM, J. O. Symposium: Mentality in machines. In Aristotelian Society, Suppl. Vol. 26, *Men and machines.* London: Harrison, 1952. Pp. 1–26.

WOODWORTH, R. S. *Psychology.* New York: Holt, 1921.

WOODWORTH, R. S., & SCHLOSBERG, H. *Experimental psychology.* (Rev. ed.) New York: Holt, 1954.

WRIGHT, S., Physiological genetics, ecology of populations, and natural selection. *Perspectives Biol. Med.,* 1959, **3**, 107–151. (Reprinted: Tax, S. (Ed.) *Evolution after Darwin.* Vol. I. *The evolution of life.* Chicago: Univer. Chicago Press, 1960.)

(Received October 21, 1959)