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EVOLUTIONARY EPISTEMOLOGY*

An evolutionary epistemology would be at minimum an epistemology taking cognizance of and compatible with man's status as a product of biological and social evolution. In the present essay it is also argued that evolution—even in its biological aspects—is a knowledge process, and that the natural-selection paradigm for such knowledge increments can be generalized to other epistemic activities, such as learning, thought, and science. Such an epistemology has been neglected in the dominant philosophic traditions. It is primarily through the works of Karl Popper that a natural selection epistemology is available today.

Much of what follows may be characterized as "descriptive epistemology," descriptive of man as knower. However, a correct descriptive epistemology must also be analytically consistent. Or, vice versa, of all of the analytically coherent epistemologies possible, we are interested in those (or that one) compatible with the description of man and of the world provided by contemporary science. Modern biology teaches us that man has evolved from some simple unicellular or virus-like ancestor and its still simpler progenitors. In the course of that evolution, there have been tremendous gains in adaptive adequacy, in stored templates modeling the useful stabilities of the environment, in memory and innate wisdom. Still more dramatic have been the great gains in mechanisms for knowing, in visual perception, learning, imitation, language and science. At no stage has there been any transfusion of knowledge from the outside, nor of mechanisms of knowing, nor of fundamental certainties.

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An analytically coherent epistemology could perhaps be based upon a revelation to Adam of true axioms and deductive logic, from which might be derived, perhaps in conjunction with observations, man's true knowledge. Such an epistemology would not be compatible with the evolutionary model. Nor, would be a direct realism, an epistemology assuming veridical visual perception, unless that epistemology were also compatible with the evolution of the eye from a series of less adequate prior stages back to a light-sensitive granule of pigment. Also incompatible would be a founding of certainty on the obviously great efficacy of ordinary language. In the evolutionary perspective, this would either commit one to a comparable faith in the evolutionary prestages to modern language, or to a discontinuity and point of special creation. Better to recognize the approximate and only pragmatic character of language at all stages, including the best. An analytic epistemology appropriate to man's evolved status must be appropriate to these evolutionary advances and to these prior stages, as well as to modern man.

We once "saw" as through the fumblings of a blind protozoan, and no revelation has been given to us since. Vision represents an opportunistic exploitation of a coincidence which no deductive operations on a protozoan's knowledge of the world could have anticipated. This is the coincidence of locomotor impenetrability with opaqueness, for a narrow band of electromagnetic waves. For this band, substances like water and air are transparent, in coincidental parallel with their locomotor penetrability. For other wave lengths, the coincidence, and hence the cue value, disappears. The accidental encountering and systematic cumulations around this coincidence have provided in vision a wonderful substitute for blind exploration. In this perspective, clear glass and fog are paradoxical—glass being impenetrable but transparent, fog being the reverse. Glass was certainly lacking in the ecology of evolution. Fog was rare or nonexistent in the aqueous environment of the fish where most of this evolution took place. (Modern man corrects the paradoxical opacity of fog through exploiting another coincidence in the radar wave bands.) The visual system is furthermore far from perfect, with usually overlooked inconsistencies such as double images for nonfixated objects, blind spots, optical illusions, chromatic aberration, astigmatism, venous shadows, etc.

In all of this opportunistic exploitation of coincidence in vision there is no logical necessity, no absolute ground for certainty, but instead a most back-handed indirectness. From this perspective, Hume's achievement in showing that the best of scientific laws have neither analytic truth nor any other kind of absolute truth seems quite reasonable and appropriate. Here description and analysis agree.

1. The Selective Elimination Model

The advances produced in the course of evolution are now seen as due to natural-selection, operating upon the pool of self-perpetuating variations which the genetics of the breeding group provide, and from within this pool, differentially propagating some variations at the expense of others. The supply of variations comes both from mutations providing new semistable molecular arrangements of the genetic material and from new combinations of existing genes. Considered as improvements or solutions, none of these variations has any a priori validity. None has the status of revealed truth nor of analytic deduction. Whatever degree of validation emerges comes from the differential surviving of a winnowing, weeding-out, process.

Popper's first contribution to an evolutionary epistemology is to recognize the process of the succession of theories in science as a similar selective elimination process. The theme is expressed clearly, if but in passing, in the 1934 *Logik der Forschung*. Here are two relevant passages:

> According to my proposal, what characterizes the empirical method is its manner of exposing to falsification, in every conceivable way, the system to be tested. Its aim is not to save the lives of untenable systems but, on the contrary, to select the one which is by comparison the fittest, by exposing them all to the fiercest struggle for survival.[1]
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> . . . How and why do we accept one theory in preference to others?
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> The preference is certainly not due to anything like an experiential justification of the statements composing the theory; it is not due to a logical reduction of the theory to experience. We choose the theory which best holds its own in competition with other theories; the one which, by natural selection, proves itself the fittest to survive. This will be the one which not only has hitherto stood up to the severest tests, but the one which is also testable in the most rigorous way. A theory is a tool which we test by applying it, and which we judge as to its fitness by the results of its applications.[2]

Fuller expressions of this evolutionary epistemology were contained in his unpublished manuscript of 1932, *Die beiden Grundprobleme der Erkenntnistheorie* (subsequently titled *Das Problem: die Erkenntnistheorie der Naturgesetzlichkeit*). In later publications, especially as collected in *Conjectures and Refutations*,[3] the theme is more explicitly presented and elaborated.

These additions add trial-and-error learning by man and animals to the prototypic illustrations of his basic logic of inference (logic of discovery, logic of the expansion of knowledge). They make explicit his willingness to identify the process of knowledge with the whole evolutionary sequence.

> Without waiting, passively, for repetitions to impress or impose regularities upon us, we actively try to impose regularities upon the world. We try to discover similarities in it, and to interpret it in terms of laws invented by us. Without waiting for premises we jump to conclusions. These may have to be discarded later, should observation show that they are wrong.

This was a theory of trial and error—of *conjectures and refutations*. It made it possible to understand why our attempts to force interpretations upon the world were logically prior to the observation of similarities. Since there were logical reasons behind this procedure, I thought that it would apply in the field of science also; that scientific theories were not the digest of observations, but that they were inventions—conjectures boldly put forward for trial, to be eliminated if they clashed with observations; with observations which were rarely accidental but as a rule undertaken with the definite intention of testing a theory by obtaining, if possible, a decisive refutation.[4]

Hume was right in stressing that our theories cannot be validly inferred from what we can know to be true—neither from observations nor from anything else. He concluded from this that our belief in them was irrational. If 'belief' means here our inability to doubt our natural laws, and the constancy of natural regularities, then Hume is again right: this kind of dogmatic belief has, one might say, a physiological rather than a rational basis. If, however, the term 'belief' is taken to cover our critical acceptance of scientific theories—a *tentative* acceptance combined with an eagerness to revise the theory if we succeed in designing a test which it cannot pass—then Hume was wrong. In such an acceptance of theories there is nothing irrational. There is not even anything irrational in relying for practical purposes upon well-tested theories, for no more rational course of action is open to us.

Assume that we have deliberately made it our task to live in this unknown world of ours; to adjust ourselves to it as well as we can; to take advantage of the opportunities we can find in it; and to explain it, if possible (we need not assume that it is), and as far as possible, with the help of laws and explanatory theories. *If we have made this our task, then there is no more rational procedure than the method of trial and error—of conjecture and refutation*: of boldly proposing theories; of trying our best to show that these are erroneous; and of accepting them tentatively if our critical efforts are unsuccessful.[5]

The method of trial and error is not, of course, simply identical with the scientific or critical approach—with the method of conjecture and refutation. The method of trial and error is applied not only by Einstein but, in a more dogmatic fashion, by the amoeba also. The difference lies not so much in the trials as in a critical and constructive attitude towards errors; errors which the scientist consciously and cautiously tries to uncover in order to refute his theories with searching arguments, including appeals to the most severe experimental tests which his theories and his ingenuity permit him to design.[6]

In the process, Popper has effectively rejected the model of passive induction even for animal learning, and advocated that here too the typical process involves broad generalizations from single specific initial experiences, generalizations which subsequent experiences edit.[7] It is noteworthy that the best of modern mathematical learning theories posit just such a one-trial learning process, as opposed to older theories which implied inductive accumulation of evidence on all possible stimulus contingencies.[8]

Most noteworthy, Popper is unusual among modern epistemologists in taking Hume's criticism of induction seriously, as more than an embarrassment, tautology, or a definitional technicality. It is the logic of variation and selective elimination which has made him able to accept Hume's contribution to analysis (while rejecting Hume's contribution to the psychology of learning

and inference) and to go on to describe that sense in which animal and scientific knowledge is yet possible.

2. *Locating the Problem of Knowledge*

It is well to be explicit that involved in Popper's achievement is a recentering of the epistemological problem. As with Hume, the status of scientific knowledge remains important. The conscious cognitive contents of an individual thinker also remain relevant. But these no longer set the bounds of the problem. The central requirement becomes an epistemology capable of handling *expansions* of knowledge, *breakouts* from the limits of prior wisdom, *scientific discovery*. While one aspect of this general interest is descriptive, central to Popper's requirement is a logical epistemology which is compatible with such growth.

The central problem of epistemology has always been and still is the problem of the growth of knowledge. And the growth of knowledge can be studied best by studying the growth of scientific knowledge . . . . A little reflection will show that most problems connected with the growth of our knowledge must necessarily transcend any study which is confined to common-sense knowledge as opposed to scientific knowledge. For the most important way in which common-sense knowledge grows is, precisely, by turning into scientific knowledge. Moreover, it seems clear that the growth of scientific knowledge is the most important and interesting case of the growth of knowledge.

It should be remembered, in this context, that almost all the problems of traditional epistemology are connected with the problem of the growth of knowledge. I am inclined to say even more: from Plato to Descartes, Leibnitz, Kant, Duhem, and Poincaré; and from Bacon, Hobbes, and Locke to Hume, Mill, and Russell, the theory of knowledge was inspired by the hope that it would enable us not only to know more about knowledge, but also to contribute to the advance of knowledge—of scientific knowledge, that is.[9]

I now turn to the last group of epistemologists—those who do not pledge themselves in advance to any philosophical method, and who make use, in epistemology, of the analysis of scientific problems, theories, and procedures, and, most important, of scientific discussions. This group can claim, among its ancestors, almost all the great philosophers of the West. (It can claim even the ancestry of Berkeley despite the fact that he was, in an important sense, an enemy of the very idea of rational scientific knowledge, and that he feared its advance.) Its most important representatives during the last two hundred years were Kant, Whewell, Mill, Peirce, Duhem, Poincaré, Meyerson, Russell, and—at least in some of his phases—Whitehead. Most of those who belong to this group would agree that scientific knowledge is the result of the growth of common-sense knowledge. But all of them discovered that scientific knowledge can be more easily studied than common-sense knowledge. For it is *common-sense knowledge writ large*, as it were. Its very problems are enlargements of the problems of common-sense knowledge. For example, it replaces the Humean problem of 'reasonable belief' by the problem of the reasons for accepting or rejecting scientific theories. And since we possess many detailed reports of the discussions pertaining to the problem whether a theory such as Newton's or Maxwell's or Einstein's should be accepted or rejected, we may look at these discussions as if through a microscope that allows us to study in detail, and objectively, some of the more important problems of 'reasonable belief.'

This approach to the problems of epistemology gets rid . . of the pseudo-psychological or 'subjective' method of the new way of ideas (a method still used by Kant). But it also allows us to analyse scientific problem-situations and scientific discussions. And it can help us to understand the history of scientific thought.[10]

A focus on the growth of knowledge, on acquisition of knowledge, makes it appropriate to include learning as well as perception as a knowledge process. Such an inclusion makes relevant the learning processes of animals. However primitive these may be, they too must conform to an adequate logical epistemology. Animal learning must not be ruled out as impossible by the logic of knowing.[11] Popper notes these broader bounds to the epistemological problem in numerous places in *Conjectures and Refutations*, for example:

> Although I shall confine my discussion to the growth of knowledge in science, my remarks are applicable without much change, I believe, to the growth of pre-scientific knowledge also—that is to say, to the general way in which men, and even animals, acquire new factual knowledge about the world. The method of learning by trial and error—of learning from our mistakes—seems to be fundamentally the same whether it is practised by lower or by higher animals, by chimpanzees or by men of science. My interest is not merely in the theory of scientific knowledge, but rather in the theory of knowledge in general. Yet the study of the growth of scientific knowledge is, I believe, the most fruitful way of studying the growth of knowledge in general. For the growth of scientific knowledge may be said to be the growth of ordinary human knowledge *writ large*.[12]

Such a location of the epistemological problem differs strikingly from traditional views, even though overlapping them. Given up is the effort to hold all knowledge in abeyance until the possibility of knowledge is first logically established, until indubitable first principles or incorrigible sense data are established upon which to build. Rather, the cumulative achievement of logical analysis is accepted: such grounds are logically unavailable. No nonpresumptive knowledge and no nonpresumptive modes of knowing are possible to us. The difference between science and fiction, or between truth and error, must lie elsewhere, as in the tests and outcomes of testing of the logical implications of the presumptions. No claims to the refutation of a consistent (and therefore unspoken) solipsism is made. The logical irrefutability of such a possibility is accepted. The problem of knowledge, however, is elsewhere—in truth claims descriptive of a more than now-phenomenal world. This presumptive descriptive character is as inextricable in "direct" observation as in the statement of laws. The interest in the primitive fundamentals of knowledge does not begin or end with the conscious contents or sense-data of the philosopher himself.

Another older and also more current statement of the epistemological problem is also eschewed. This is the identification of "knowledge" not as "true belief" but as "true belief" which is also "rationally justified" or "well-grounded." Though widely used in linguistic analysis, this point of view implicitly accepts as valid an inductivist epistemology (giving but superficial lip service to Hume in recognizing such induction as providing only approximate validity). Popper does not limit truth to those statements which have rational support or are well-grounded before they are asserted. Truth rather lies in the outcome of subsequent tests.

> *We do not know: we can only guess.* And our guesses are guided by the unscientific, the metaphysical (though biologically explicable) faith in laws, in regularities which we can uncover—discover. Like Bacon, we might describe our own contemporary science—'the method of reasoning which men now ordinarily apply to nature'—as consisting of 'anticipations, rash and premature' and as 'prejudices'.
>
> But these marvelously imaginative and bold conjectures or 'anticipations' of ours are carefully and soberly controlled by systematic tests. Once put forward, none of our 'anticipations' are dogmatically upheld. Our method of research is not to defend them, in order to prove how right we were. On the contrary, we try to overthrow them. Using all the weapons of our logical, mathematical, and technical armory we try to prove that our anticipations were false—in order to put forward, in their stead, new unjustified and unjustifiable anticipations, new 'rash and premature prejudices'.[13]

3. A Nested Hierarchy of Selective-Retention Processes

Human knowledge processes, when examined in continuity with the evolutionary sequence, turn out to involve numerous mechanisms at various levels of substitute functioning, hierarchically related, and with some form of selective retention process at each level. While Popper has for most of his career been more interested in the logic of knowing than in a descriptive epistemology, in *Of Clouds and Clocks* he has expanded his evolutionary perspective along these lines. This is a paper which should be read by both epistemologists and those interested in problems of purpose and teleology. A few brief quotations from it will serve to introduce the present section.

> My theory may be described as an attempt to apply to the whole of evolution what we learned when we analysed the evolution from animal language to human language. And it consists of a certain *view of evolution* as a growing hierarchical system of plastic controls, and of a certain *view of organisms* as incorporating—or in the case of man, evolving exosomatically—this growing hierarchical system of plastic controls. The Neo-Darwinist theory of evolution is assumed; but it is restated by pointing out that its 'mutations' may be interpreted as more or less accidental trial-and-error gambits, and 'natural selection' as one way of controlling them by error-elimination.[14]

He also emphasizes what are called here vicarious selectors:

> Error-elimination may proceed either by the complete elimination of unsuccessful forms (the killing-off of unsuccessful forms by natural selection) or by the (tentative) evolution of controls which modify or suppress unsuccessful organs, or forms of behavior, or hypotheses.[15]
>
> Our schema allows for the development of error-eliminating controls (warning organs like the eye; feed-back mechanisms); that is, controls which can eliminate errors without killing the organism; and it makes it possible, ultimately, for our hypotheses to die in our stead.[16]

Also important is his emphasis on the multiplicity of trials needed at each error-elimination level, the necessity for the profuse generation of "mistakes."

More generally, in *Clouds and Clocks,* Popper has spoken for that emerging position in biology and control theory which sees the natural selection paradigm as the universal nonteleological explanation of teleological achievements, of ends-guided processes, of "fit."[17] Thus crystal formation is seen as the result of a chaotic permutation of molecular adjacencies, some of which are much more difficult to dislodge than others. At temperatures warm enough to provide general change, but not so warm as to disrupt the few stable adjacencies, the number of stable adjacencies will steadily grow even if their occurrence is but a random affair. In crystal formation the material forms its own template. In the genetic control of growth, the DNA provides the initial template selectively accumulating chance fitting RNA molecules, which in turn provide the selective template selectively cumulating from among chaotic permutations of proteins. These molecules of course fit multiple selective criteria: of that finite set of semistable combinations of protein material, they are the subset fitting the template. The template guides by selecting from among the mostly unstable, mostly worthless possibilities offered by thermal noise operating on the materials in solution. Turning the model to still lower levels of organization, elements and subatomic particles are seen as but nodes of stability which at certain temperatures transiently select adjacencies among still more elementary stuff.

Turning to higher levels, the model can be applied to such dramatically teleological achievements as embryological growth and wound healing. Within each cell, genetic templates for all types of body proteins are simultaneously available, competing as it were for the raw material present. Which ones propagate most depends upon the surrounds. Transplantation of embryonic material changes the surroundings and hence the selective system. Wounds and amputations produce analogous changes in the "natural selection" of protein possibilities. Spiegelman[18] has specifically noted the Darwinian analogy and its advantages over vitalistic teleological pseudoexplanations which even concepts of force fields and excitatory gradients may partake of.

Regeneration provides an illustration of the nested hierarchical nature of biological selection systems. The salamander's amputated leg regrows to a length optimal for locomotion and survival. The ecological selection system does not operate directly on the leg length however. Instead, the leg length is selected to conform to an internal control built into the developmental system which vicariously represents the ecological selective system. This control was itself selected by the trial and error of whole mutant organisms.[19] If the ecology has recently undergone change, the vicarious selective criterion will correspondingly be in error. This larger, encompassing selection system is the organism-environment interaction. Nested in a hierarchial way within it is the selective system directly operating on leg length, the "settings" or criteria for which are themselves subject to change by natural selection. What are criteria at one level are but "trials" of the criteria of the next higher, more fundamental, more encompassing, less frequently invoked level.

In other writings[20] the present author has advocated a systematic extrapolation of this nested hierarchy selective retention paradigm to *all* knowledge processes, in a way which, although basically compatible with Popper's orientation, may go farther than he would find reasonable in extremity, dogmatism and claims for generality. It may on these same grounds alienate the reader. (Disagreement at this point will not rule out accepting later propositions.)

1. A blind-variation-and-selective-retention process is fundamental to all inductive achievements,[21] to all genuine increases in knowledge, to all increases in fit of system to environment.

2. In such a process there are three essentials: (a) Mechanisms for introducing variation; (b) Consistent selection processes; and (c) Mechanisms for preserving and/or propagating the selected variations. Note that in general the preservation and generation mechanisms are inherently at odds, and each must be compromised.

3. 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.

4. 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.

The word "blind" is used rather than the more ususal "random" for a variety of reasons. It seems likely that Ashby[22] unnecessarily limited the generality of his mechanism in Homeostat by an effort fully to 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, although 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. 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.)[23]

While most descriptions of discovery and creative processes recognize the need for variation, the present author's dogmatic insistence on the blindness of such variation seems generally unacceptable. As will be seen in what follows, particularly in the discussions of vision and thought, there is no real descriptive disagreement. The present writer agrees that the overt responses of a problem-solving animal in a puzzle box are far from random, and this for several reasons: 1. Already achieved wisdom of a general sort which limits the range of trials (such wisdom due to inheritance and learning). 2. Maladaptive restriction on the range of trials. (Such biases due to structural limitations and to past habit and instinct inappropriate in a novel environment.) But these first two reasons will characterize the wrong responses as well as the correct ones, and offer no explanation of the correctness of the correct one. 3. Vicarious selection, appropriate to the immediate problem, achieved through vision. (See the subsequent section on this topic.) When, in considering creative thought, Poincaré is followed, allowing for unconscious variation-and-selection processes, opportunity for descriptive disagreement is further reduced. The point is not empirically empty, however, as it sets essential limits and requirements for any problem-solving computer (discussed under Thought, below). But the point is also analytic. In going beyond what is already known, one cannot but go blindly. If one can go wisely, this indicates already achieved wisdom of some general sort.

Expanding this orientation and applying it to the setting of biological and social evolution, a set of ten more or less discrete levels can be distinguished, and these are elaborated in the following sections.

1. *Nonmnemonic problem solving.* At the level of Jennings's[24] paramecium, stentor, and Ashby's[25] Homeostat, there is a blind variation of locomotor activity until a setting that is nourishing or nonnoxious is found. Such problem-solutions are then retained as a cessation of locomotion, as a cessation of variation. There is, however, no memory, no using of old

solutions over again. Ashby deliberately took Jennings's paramecium as his model, and describes the natural selection analogy at this level as follows:

> The work also in a sense develops a theory of the "natural selection" of behaviour-patterns. 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. Just as the gene pattern in its encounters with the environment tends toward ever better adaptation of the inherited form and function, so does a system of step- and part-functions tend toward ever better adaptation of learned behavior.[26]

In a world with only benign or neutral states, an adaptive organism might operate at this level without exteroceptors. Wherever it is, it is trying to ingest the immediate environment. When starvation approaches, blind locomotor activity is initiated, ingestion being attempted at all locations. Even at this level, however, there is needed an interoceptive sense organ which monitors nutritional level, and substitutes for the whole organism's death. In the actual case of Jennings's stentor, chemoreceptors for noxious conditions are present, vicarious representatives of the lethal character of the environment, operating on nonlethal samples or signs of that environment. It is these chemoreceptors and comparable organs which in fact provide the immediate selection of responses. Only indirectly, through selecting the selectors, does life-and-death relevance select the responses.

At this level of knowing, however, the responses may be regarded as direct rather than vicarious. And, as to presuppositions about the nature of the world (the ontology guiding epistemology), perhaps all that is assumed is spatial discontinuity somewhat greater than temporal discontinuity in the distribution of environmental substances: moving around is judged to bring changes more rapidly than staying put. 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. The animal has "learned" that there are some solvable problems. Already the machinery of knowing is biasedly focused upon the small segment of the world which is knowable, as natural selection makes inevitable.

2. *Vicarious locomotor devices.* Substituting for spatial exploration by locomotor trial and error are a variety of distance receptors of which a ship's radar is an example. An automated ship could explore the environment of landfalls, harbors and other ships by a trial and error of full movements and collisions. Instead, it sends out substitute locomotions in the form of a radar beam. These are selectively reflected from nearby objects, the reflective opaqueness to this wave band vicarioully representing the locomotor impenetrability of the objects. This vicarious representability is a contingent dis-

covery, and is in fact only approximate. The knowledge received is reconfirmed as acted upon by the full ship's locomotion. The process removes the trial-and-error component from the overt locomotion, locating it instead in the blindly emitted radar beam. (The radar beam is not emitted randomly, but it could be so emitted and still work. The radar beam is, however, emitted in a blind exploration, albeit a systematic sweep.) Analogous to radar and to sonar are several echolocation devices in animals. Pumphrey has described the lateral-line organ of fish as a receiver for the reflected pulses of the broadcast pressure waves emitted by the fish's own swimming movements. The all-directional exploring of the wave front is selectively reflected by nearby objects, pressure wave substituting for locomotor exploration. The echolocation devices of porpoises, bats, and cave birds have a similar epistemology.[27]

Assimilating vision to the blind-variation-and-selective-retention model is a more difficult task.[28] It seems important, however, to make vision palpably problematic, in correction of the common sense realism or the direct realism of many contemporary philosophers which leads them to an uncritical assumption of directness and certainty for the visual process. The vividness and phenomenal directness of vision needs to be corrected in any complete epistemology, which also has to make comprehensible how such an indirect, coincidence-exploiting mechanism could work at all. Were visual percepts as vague and incoherent as the phosphors on a radar screen, many epistemological problems would be avoided. From the point of view of an evolutionary epistemology, vision is just as indirect as radar.

Consider a one-photocell substitute eye such as was once distributed for the use of the blind. To an earphone, the cell transmitted a note of varying pitch depending upon the brightness of the light received. In blind search with this photocell, one could locate some objects and some painted boundaries on flat surfaces, all boundaries being indicated by a shift in tone. One can imagine an extension of this blind search device to a multiple photocell model, each photocell of fixed direction, boundaries being located by a comparison of emitted tones or energies perhaps in some central sweep scanning of outputs. To be sure, boundaries would be doubly confirmed if the whole set were oscillated slightly, so that a boundary stood out not only as comparison across adjacent receptors at one time, but also as a comparision across times for the same receptors. (The eye has just such a physiological nystagmus, essential to its function.) Similarly, one could build a radar with multiple fixed-directional emitters and receivers. It would search just as blindly, just as openmindedly, as the single beam and sweep scanner. In such multiple receptor devices, the opportunities for excitation are blindly made available and are selectively activated.

Blind locomotor search is the more primary, the more direct exploration. A blind man's cane is a vicarious search process. The less expensive cane movements substitute for blind trials and wasted movements by the whole

body, removing costly search from the full locomotor effort, making that seem smooth, purposeful, insightful.[29] The single photocell device seems equally blind, although utilizing a more unlikely substitute, one still cheaper in effort and time. The multiple photocell device, or the eye, uses the multiplicity of cells instead of a multiplicity of focusings of one cell, resulting in a search process equally blind and open-minded, equally dependent upon a selection-from-variety epistemology. The substitutability of cane locomotion for body locomotion, the equivalence of opaque-to-cane and opaque-to-body, is a contingent discovery, although one which seems more nearly "entailed," or to involve a less complex, less presumptive model of the physical world than does the substitutability of light waves or radar waves for body locomotion.

This is, of course, a skeletonized model of vision, emphasizing its kinship to blind fumbling, and its much greater indirectness than blind fumbling, phenomenal directness notwithstanding. Neglected is the presumptive achievement of the visual system in reifying stable discrete objects, stable over a heterogeneity of points of viewing; neglected is the fundamental epistemological achievement of "identifying" new and partially different sets of sense data as "the same" so that habit or instinct or knowledge can be appropriately applied even though there be no logically entailed identity.[30]

3. *Habit* and 4. *Instinct.* Habit, instinct, and visual diagnosis of objects are so interlocked and interdependent that no simple ordering of the three is possible. Much more detailed work is needed on the evolution of knowledge processes, and such an examination would no doubt describe many more stages than are outlined here. Such a study could also profitably describe the "presumptions" about the nature of the world, or the "knowledge" about the nature of the world, underlying each stage. Certainly the extent of these presumptions is greater at the more advanced levels.

The visual diagnosis of reindentifiable objects is basic to most instinctive response patterns in insects and vertebrates, both for instigation of the adaptive pattern and for eliminating the trial-and-error component from the overt response elements. In a crude way, instinct development can be seen as involving a trial and error of whole mutant animals, whereas trial-and-error learning involves the much cheaper wastage of responses within the lifetime of a single animal.[31] The same environment is editing habit and instinct development in most cases, the editing process is analogous, and the epistemological status of the knowledge, innate or learned, no different. Thus the great resistance of the empiricists to innate knowledge is made irrelevant, but in the form of a more encompassing empiricism. It can be noted that all comprehensive learning theories, including those of Gestalt inspiration, contain a trial-and-error component, be it a trial and error of "hypotheses" or "recenterings."[32]

These general conclusions may be acceptable, but the evolutionary discreteness of the two processes is not as clear as implied nor should instinct necessarily be regarded as more primitive than habit. Complex adaptive instincts typically involve multiple movements and must inevitably involve a multiplicity of mutations at least as great in number as the obvious movement segments. Furthermore, it is typical that the fragmentary movement segments, or the effects of single component mutations, would represent no adaptive gain at all apart from the remainder of the total sequence. The joint likelihood of the simultaneous occurrence of the adaptive form of the many mutations involved is so infinitesimal that the blind-mutation-and-selective-retention model seems inadequate. This argument was used effectively by both Lamarckians and those arguing for an intelligently guided evolution or creation. Baldwin, Morgan, Osborn, and Poulton[33] believing that natural selection was the adequate and only mechamism, proposed that for such instincts, learned adaptive patterns, recurrently discovered in similar form within a species by trial-and-error learning, preceded the instincts. The adaptive pattern being thus piloted by learning, any mutations that accelerated the learning, made it more certain to occur, or predisposed the animal to certain component responses, would be adaptive and selected no matter which component, or in what order affected. The habit thus provided a selective template around which the instinctive components could be assembled. (Stating it in other terms, learned habits make a new ecological niche available which niche then selects instinct components.) It is furthermore typical of such instincts that they involve learned components, as of nest and raw material location, etc.

This can be conceived as an evolution of increasingly specific selection-criteria, which at each level select or terminate visual search and trial-and-error learning. In what we call learning, these are very general drive states and reinforcing conditions. In the service of these general reinforcers, specific objects and situations become learned goals and subgoals, learned selectors of more specific responses. (Even for drives and reinforcers, of course, the environment's selective relevance is represented indirectly, as in the pleasureableness of sweet foods, the vicariousness of which is shown by an animal's willingness to learn for the reward of nonnutritive saccharine.) In the habit-to-instinct evolution, the once-learned goals and subgoals become innate at a more and more specific response-fragment level. For such an evolutionary development to take place, very stable environments over long evolutionary periods are required.

Popper in his Herbert Spencer Lecture of 1961[33a] makes a creative analysis of the evolution of purposeful behavior which in some ways parallels Baldwin's, but is more explicit on the hierarchial selection of selectors. Using a servomechanism model of an automated aeroplane, he suggests that mutations of "aim-structure" precede and subsequently select mutations in "skill structure."

5. *Visually supported thought.* The dominant form of insightful problem solving in animals, e.g., as described by Köhler,[34] requires the support of a visually present environment. With the environment represented vicariously through visual search, there is a substitute trial and error of potential locomotions in thought. The "successful" locomotions at this substitute level, with its substitute selective criteria, are then put into overt locomotion, where they appear "intelligent," "purposeful," "insightful," even if still subject to further editing in the more direct contact with the environment.

6. *Mnemonically supported thought.* At this level the environment being searched is vicariously represented in memory or "knowledge," rather than visually, the blindly emitted vicarious thought trials being selected by a vicarious criterion substituting for an external state of affairs. The net result is the "intelligent," "creative," and "foresightful" product of thought, our admiration of which makes us extremely reluctant to subsume it under the blind-variation-and-selective-retention model. Yet it is in the description of this model that the trial-and-error theme, the blind permutation theme, has been most persistently invoked. When Mach in 1895 was called back to Vienna to assume the newly created professorship in "The History and Theory of Inductive Sciences," he chose this topic:

> The disclosure of new provinces of facts before unknown can only be brought about by accidental circumstances . . .[35]
>
> . . . 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.[36]
>
> . . . 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.[37]

Poincaré's famous essay on mathematical creativity espouses such a view at length, arguing that it is mathematical beauty which provides the selective criteria for a blind permuting process usually unconscious:

> 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.[38]
>
> . . . 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.[39]

. . . 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 to 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.[40]

. . . 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.[41]

Alexander Bain was proposing a trial-and-error model of invention and thought as early as 1855.[42] Jevons in 1874[43] was advocating a similar model in the context of a rejection of Bacon's principle of induction on grounds similar to Popper's.

I hold that in all cases of inductive inference we must invent hypotheses until we fall upon some hypothesis which yields deductive results in accordance with experience.[44]

It would be an error to suppose that the great discoverer seizes at once upon the truth or has any unerring method of divining it. In all probability the errors of the great mind exceed in number those of the less vigorous one. Fertility of imagination and abundance of guesses at truth are among the first requisites of discovery; but the erroneous guesses must be many times as numerous as those which prove well founded. The weakest analogies, the most whimsical notions, the most apparently absurd theories, may pass through the teeming brain, and no record remain of more than the hundredth part. There is nothing really absurd except that which proves contrary to logic and experience. The truest theories involve suppositions which are inconceivable, and no limit can really be placed to the freedom of hypothesis.[45]

In his very modern and almost totally neglected *Theory of Invention* of 1881, Souriau effectively criticizes deduction, induction, and *"la methode"* as models for advances in thought and knowledge. His recurrent theme is *"le principe de l'invention est le hazard"*:

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.[46]

By a kind of artificial selection, we can in addition substantially perfect our thought and make it more and more logical. Of all 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.[47]

. . . 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.[48]

Note the similarity of the imagery in the final paragraph with that of Ashby as cited under level 1, above, and that of Poincaré, Mach and Jevons. In Souriau's use of the phrase "artificial selection," he seems to refer to the analogy with Darwin's theory of natural selection, but we cannot be certain. Souriau's book is totally devoid of citations or even mentions of the works of any other. William James, however, is completely explicit on the analogy in an article published in 1880.[49] Arguing against Spencer's model of a perfectly passive mind, he says:

And I can easily show that throughout the whole extent of those mental departments which are highest, which are most characteristically human, Spencer's law is violated at every step; and that, as a matter of fact, the new conceptions, emotions, and active tendencies which evolve are orginally *produced* in the shape of random images, fancies, accidental outbirths of spontaneous variation in the functional activity of the excessively unstable human brain, which the outer environment simply confirms or refutes, preserves or destroys—selects, in short, just as it selects morphological and social variations due to molecular accidents of an analogous sort.[50]

. . . . The conception of the [scientific] law is a spontaneous variation in the strictest sense of the term. It flashes out of one brain, and no other, because the instability of that brain is such as to tip and upset itself in just that particular direction. But the important thing to notice is that the good flashes and the bad flashes, the triumphant hypotheses and the absurd conceits, are on an exact equality in respect of their origin.[51]

James departs from the more complete model presented in Poincaré,[52] Mach,[53] and Campbell[54] by seemingly having the full range of mental variations selected by the external environment rather than recognizing the existence of mental selectors, which vicariously represent the external environment. (The selected products, of course, being subject to further validation in overt locomotion, etc.)

Among the many others who have advocated such a view are Baldwin, Fouillé, Pillsbury, Woodworth, Rignano, Thurstone, Lowes, Tolman, Hull, Muenzinger, Miller and Dollard, Boring, Humphrey, Mowrer, Sluckin, Pólya and Bonsack.[55] One presentation which has reached the attention of some philosophers is that of Kenneth J. W. Craik, in his fragmentary work of genius, *The Nature of Explanation*,[56] a work which in many other ways also espouses an evolutionary epistemology.

The resultant process of thought is a very effective one, and a main pillar of man's high estate. Yet it must be emphasized again that the vicarious representations involved—both environmental realities and potential locomotions being represented in mind-brain processes—are discovered contingent relationships, achieving no logical entailment, and in fine detail incomplete and imperfect. This same vicarious, contingent, discovered, marginally imperfect representativeness holds for the highly selected formal logics and mathematics which we utilize in the processes of science.

Computer problem solving is a highly relevant topic, and is perhaps best introduced at this point. Like thinking, it requires vicarious explorations of a vicarious representation of the environment, with the exploratory trials being selected by criteria which are vicarious representatives of solution requirements or external realities. The present writer would insist here too, that if discovery or expansions of knowledge are achieved, blind variation is requisite. This being the case, it is only fair to note that Herbert Simon, both a leading computer simulator of thought and an epistemologically sophisticated scholar, rejects this point of view, at least in the extreme form advocated here. For example, he says "The more difficult and novel the problem, the greater is likely to be the amount of trial and error required to find a solution. At the same time, the trial and error is not completely random or blind; it is, in fact, highly selective."[57] Earlier statements on this have been still more rejective.[58] The present writer has attempted elsewhere to answer in more detail than space here permits,[59] but a brief summary is in order. The "selectivity," insofar as it is appropriate, represents already achieved wisdom of a more general sort, and as such, selectivity does not in any sense explain an innovative solution. Insofar as the selectivity is inappropriate, it limits areas of search in which a solution might be found, and rules out classes of possible solutions. Insofar as the selectivity represents a partial general truth, some unusual solutions are ruled out. Simon's "heuristics" are such partial truths, and a computer which would generate its own heuristics would have to do so by a blind trial and error of heuristic principles, selection from which would represent achieved general knowledge. The principle of hierarchy in problem solving depends upon such discoveries, and once achieved, can, of course, greatly reduce the total search space, but without at all violating the requirement of blindness as here conceived. For example, one of the heuristics used in Simon's "Logic Theorist" program[60] is that any substitution or transformation which will increase the "similarity" between a proposition and the desired outcome should be retained as a stem on which further variations are to be tried. Any transformation decreasing similarity should be discarded. Similarity is crudely scored by counting the number of identical terms, with more points for similarity of location. This rule enables selection to be introduced at each transformational stage, greatly reducing the total search space. It employs an already achieved partial truth. It produces computer search similar to human problem solving in failing to discover roundabout solutions requiring initial decreases in similarity. Beyond thus applying what is already known, albeit only a partial truth, the new discoveries must be produced by a blind generation of alternatives.

7. *Socially vicarious exploration: observational learning and imitation.* The survival value of the eye is obviously related to an economy of cognition—the economy of eliminating all of the wasted locomotions which would otherwise be needed. An analogous economy of cognition helps account for the great survival advantage of the truly social forms of animal life, which in evolutionary sequences are regularly found subsequent to rather than prior to solitary forms. In this, the trial-and-error exploration of one member of a group substitutes for, renders unnecessary, trial-and-error exploration on the part of other members. The use of trial and error by scouts on the part of migrating social insects and human bands illustrates this general knowledge process. At the simplest level in social animals are procedures whereby one animal can profit from observing the consequences to another of that other's acts, even or especially when these acts are fatal to the model. The aversion which apes show to dismembered ape bodies, and their avoidance of the associated locations, illustrates such a process.[61] In ants and termites the back tracking on the tracks of foragers who have come back heavy laden illustrates such a process for knowledge of attractive goal objects. The presumptions involved in this epistemology include the belief that the model, the vicar, is exploring the same world in which the observer is living and locomoting, as well as those assumptions about the lawfulness of that world which underlie all learning.

Also noted in social animals, perhaps particularly in their young, is a tendency to imitate the actions of models even when the outcomes of those actions cannot be observed. This is a much more presumptive, but still "rational" procedure. It involves the assumptions that the model animal is capable of learning and is living in a learnable world. If this is so, then the model has probably eliminated punished responses and has increased its tendencies to make rewarded responses, resulting in a net output of predominantly rewarded responses (the more so the longer the learning period and the stabler the environment).[62]

But even in imitation, there is no "direct" infusion or transference of knowledge or habit, just as there is no "direct" acquisition of knowledge by observation or induction. As Baldwin[63] analyzes the process, what the child acquires is a criterion image, which he learns to match by a trial and error of matchings. He hears a tune, for example, and then learns to make that sound by a trial and error of vocalizations, which he checks against the memory of the sound pattern. Recent studies of the learning of bird song confirm and elaborate the same model.[64]

8. *Language.* Overlapping with levels 6 and 7 above is language, in which the outcome of explorations can be relayed from scout to follower with neither the illustrative locomotion nor the environment explored being present, not even visually-vicariously present. From the social-functional point of view, it is quite appropriate to speak of the "language" of bees, even though the wagging dance by which the scout bee conveys the direction, distance, and richness of his find is an innate response tendency automatically elicited without conscious intent to communicate. This bee language has the social function of economy of cognition in a way quite analogous to human language. The vicarious representabilities of geographical direction (relative to the sun and plane of polarization of sunlight), of distance, and of richness by features of the dance such as direction on a vertical wall, length of to-and-fro movements, rapidity of movements, etc., are all invented and contingent equivalences, neither entailed nor perfect, but tremendously reductive of flight lengths on the part of the observing or listening worker bees.[65] The details of von Frisch's analysis are currently being both challenged and extended. Perhaps the dance language does not communicate as precisely as he thought. Perhaps sonic, supersonic, and odor-trail means are also involved. It seems certain, however, that there are effective means of transmitting to other bees the successful outcomes of scout bee explorations in such a manner as to greatly reduce the total wasted exploratory effort over that required of solitary bees.

Given the present controversy over "bee language," it may be well to make the point of a functional-linguistic feature in social insects at a more primitive level. Ants and termites have independently discovered the use of pheromones for this purpose: an explorer who has encountered food exudes a special external hormone on his walk back to the nest. The other workers backtrack on this special scent. If they too are successful, if the food supply

remains plentiful, they keep the pheromone track renewed. The "knowledge" of the environment upon which the worker bases his trip is profoundly indirect. This "knowledge" is more directly confirmed if and when the worker finds food (although the also implied information that food is more prevalent in this direction than in most others is not tested at all). But even this confirmation is profoundly indirect at the individual system level, for it involves sense-organ criteria for nourishingness rather than nourishingness itself. These criteria turn out to be approximate within limits set by the prior ecology. Nonnourishing saccharin and ant poison illustrate the indirectness and proneness to illusion in novel ecologies.

For human language too, the representability of things and actions by words is a contingent discovery, a nonentailed relationship, and only approximate. We need a Popperian model of language learning in the child and of language development in the race. Regarding the child, this would emphasize that word meanings cannot be directly transferred to the child. Rather, the child must discover these by a presumptive trial and error of meanings, which the initial instance only limits but does not determine. Rather than logically complete ostensive definitions being possible, there are instead extended, incomplete sets of ostensive instances, each instance of which equivocally leaves possible multiple interpretations, although the whole series edits out many wrong trial meanings. The "logical" nature of children's errors in word usage amply testifies to such a process, and testifies against an inductionist version of a child's passively observing adult usage contingencies. This trial and error of meanings requires more than the communication of mentor and child. It requires a third party of objects referred to. Language cannot be taught by telephone, but requires visually or tactually present ostensive referents stimulating and editing the trial meanings.

Moving to the evolution of human language, a social trial and error of meanings and namings can be envisaged. Trial words designating referents which the other speakers in the community rarely guess "correctly" either fail to become common coinage or are vulgarized toward commonly guessed designations. All words have to go through the teaching sieve, have to be usefully if incompletely communicable by finite sets of ostensive instances. Stable, sharp, striking object-boundaries useful in manipulating the environment have a greater likelihood of utilization in word meanings than do subtler designations, and when used, achieve a greater universality of meaning within the community of speakers. Such natural boundaries for words exist in much greater number than are actually used, and alternate boundaries for highly overlapping concepts abound. Just as certain knowledge is never achieved in science, so certain equivalence of word meanings is never achieved in the iterative trial and error of meanings in language learning. This equivocality and heterogeneity of meanings is more than trivial logical technicality; it is a practical fringe imperfection. And even were meanings uniform, the word-to-object equivalence is a corrigible contingent relationship, a product of a trial and error of metaphors of greater and greater appropriateness, but never complete perfection, never a formal nor entailed isomorphism.[66]

9. *Cultural cumulation.* In sociocultural evolution there are a variety of variation and selective retention processes leading to advances or changes in technology and culture. Most direct, but probably of minor importance, is the selective survival of complete social organizations, differentially as a function of cultural features. More important is selective borrowing, a process which probably leads to increased adaptation as far as easily tested aspects of technology are concerned, but could involve adaptive irrelevance in areas of culture where reality testing is more difficult. Differential imitation of a heterogeneity of models from within the culture is also a selective system that could lead to cultural advance. The learning process, selective repetition from among a set of temporal variations in cultural practice, also produces cultural advance. Selective elevation of different persons to leadership and educational roles is no doubt involved. Such selective criteria are highly vicarious, and could readily become disfunctional in a changing environment.[67]

10. *Science.* With the level of science, which is but an aspect of sociocultural evolution, we return to Popper's home ground. The demarcation of science from other speculations is that the knowledge claims be testable, and that there be available mechanisms for testing or selecting which are more than social. In theology and the humanities there is certainly differential propagation among advocated beliefs, and there result sustained developmental trends, if only at the level of fads and fashions. What is characteristic of science is that the selective system which weeds out among the variety of conjectures involves deliberate contact with the environment through experiment and quantified prediction, designed so that outcomes quite independent of the preferences of the investigator are possible. It is preeminently this feature that gives science its greater objectivity and its claim to a cumulative increase in the accuracy with which it describes the world.

An emphasis on the trial-and-error nature of science is a recurrent one, perhaps more characteristic of scientists describing scientific method than of philosophers. Agassi attributes such a view to William Whewell as early as 1840: "Whewell's [is] in retrospect a Darwinian view: we must invent many hypotheses because only a few of them survive tests, and these are the ones that matter, the hard core around which research develops."[68] James, Huxley, Boltzmann, Ritchie, Jennings, Cannon, Northrop, Beveridge, Pepper, Auger, Holton, Roller, Gillispie, Caws, Ghiselin, and Monod are also among

those espousing such a view,[69] along with Toulmin, Kuhn, and Ackermann, to be discussed in more detail below.

There are a number of aspects of science which point in this direction. The opportunism of science, the rushing in and rapid development following new breakthroughs, are very like the rapid exploitation of a newly entered ecological niche. Science grows rapidly around laboratories, around discoveries which make the testing of hypotheses easier, which provide sharp and consistent selective systems. Thus the barometer, microscope, telescope, galvanometer, cloud chamber, and chromatograph all have stimulated rapid scientific growth. The necessity for the editing action of the experiment explains why a research tradition working with a trivial topic for which predictions can be checked advances more rapidly than research focused upon a more important problem but lacking a machinery for weeding out hypotheses.

A major empirical achievement of the sociology of science is the evidence of the ubiquity of simultaneous invention. If many scientists are trying variations on the same corpus of current scientific knowledge, and if their trials are being edited by the same stable external reality, then the selected variants are apt to be similar, the same discovery encountered independently by numerous workers. This process is no more mysterious than that all of a set of blind rats, each starting with quite different patterns of initial responses, learn the same maze pattern, under the maze's common editorship of the varied response repertoires. Their learning is actually their independent invention or discovery of the same response pattern. In doubly reflexively appropriateness, the theory of natural selection was itself multiply independently invented, not only by Wallace but by many others. Moreover, the ubiquity of independent invention in science has itself been independently discovered.[70]

Placing science within the selective retention theme only begins the analysis that will eventually be required, for there are within science a variety of trial-and-error processes of varying degrees of vicariousness and interdependence. At one extreme is the blindly exploratory experimentalist who within a given laboratory setting introduces variations on every parameter and combination he can think of, without attention to theory. While such activity does not epitomize science, such research often provides the empirical puzzles that motivate and discipline the efforts of theoreticians. A multiple opportunism of selective systems (or "problems") needs also to be emphasized. Whereas the mass explorations of pharmaceutical houses for new antibiotics may be single-problem oriented, "basic" research is, like biological evolution, opportunistic not only in solutions, but also in problems. The research worker encountering a new phenomenon may change his research problem to one which is thereby solved. Serendipity as described by Cannon and Merton,[71] and the recurrent theme of "chance" discovery, emphasize this double opportunism. Its occurrence implies that the scientist has an available agenda of problems, hypotheses, or expectations much larger than the specific problem on which he works, and that he is in some sense continually scanning or winnowing outcomes, particularly unexpected ones, with this larger set of sieves.

At the opposite extreme from this blind laboratory exploration is Popper's view of the natural selection of scientific theories, a trial and error of mathematical and logical models in competition with each other in the adequacy with which they solve empirical puzzles, that is, in the adequacy with which they fit the totality of scientific data and also meet the separate requirements of being theories or solutions. Popper[72] has, in fact, disparaged the common belief in "chance" discoveries in science as partaking of the inductivist belief in directly learning from experience. Although there is probably no fundamental disagreement, that issue, and the more general problem of spelling out in detail the way in which a natural selection of scientific *theories* is compatible with a dogmatic blind-variation-and-selective retention epistemology remain high priority tasks for the future.

Intermediate perhaps, is Toulmin's[73] evolutionary model of scientific development, which makes explicit analogue to population genetics and the concept of evolution as a shift in the composition of gene pool shared by a population, rather than specified in an individual. In his analogy, for genes are substituted "competing intellectual variants," concepts, beliefs, interpretations of specific fact, facts given special importance, etc. The individual scientists are the carriers. Through selective diffusion and selective retention processes some intellectual variants eventually become predominant, some completely eliminated. Some new mutants barely survive until their time is ripe.

The selective systems operating on the variations need also to be specified. As Baldwin and Peirce emphasized, the selective system of science is ultimately socially distributed in a way which any individualistic epistemology fails to describe adequately. Vicarious selectors also must be specified. Whereas the meter readings in experiments may seem to be direct selectors, this is only relatively so, and most of the proximal selection is done on the basis of vicarious criteria, including the background presumptions required to interpret the meter readings, some of which are very general in nature. In keeping with the nested hierarchy evolutionary perspective, a trial and error of such presuppositions, would be expected as part of the overall process. Both Toulmin's interpretation of the history of science in terms of shifts in what does not need to be explained and Kuhn's paradigm shifts can be interpreted in this light.[74] This is consistent with Toulmin's own evolutionary orientation. Although Kuhn also uses natural selection analogues, a natural selection of paradigms imputes to surviving paradigms a superiority over their predecessors which he explicitly questions. Ackermann has extended the evolutionary perspectives of Kuhn, Popper, and Toulmin, viewing experimental evidence as providing ecologies or niches to which theories adapt, i.e., which select theories.[75]

4. Historical Perspectives on Evolutionary Epistemology

What we find in Popper, and what has been elaborated so far, is but one type of evolutionary epistemology, perhaps best called a natural selection epistemology. As we have seen, there were both implicit and explicit forerunners of this in the nineteenth century, but they did not provide the dominant theme. Instead, theories of pre-Darwinian type generated the major evolutionary input into epistemology, even though their acceptance was furthered by the authority of Darwin's work. Herbert Spencer was the major spokesman for this school. Although he was an enthusiastic recipient of Darwin's theory of natural selection (and may even have coined the phrase "survival of the fittest"), he was a vigorous evolutionist before he read Darwin, and his thinking remained dominated by two pre-Darwinian inputs. The first was the model of embryological development, and the second was a version of Lamarckian theory in which the animal mind was a passive mirror of environmental realities. Čapek has provided three excellent historical reviews[76] of Spencer's epistemology and its influence. Among his positive contributions was his insistence that knowing had evolved along with the other aspects of life. Also valuable was his concept of the "range of correspondences," the range becoming broader at higher evolutionary stages as manifest both in distance-receptor depth and range of environmental utilization. (His evolutionary Kantianism will be discussed below.)

What Spencer missed was the profound indirectness of knowing necessitated by the natural selection paradigm, and the inevitable imperfection and approximate character of both perceptual and scientific knowledge at any stage. Instead, believing that an infinitely refinable and sensitive human cognitive apparatus had in the course of evolution adapted perfectly to the external environment, he became a naive realist accepting the givens of the cognitive processes as fundamentally valid. He also viewed human cognition as validly encompassing all reality, rather than just those aspects behaviorally relevant in the course of human evolution. Čapek sees the major limitations of Mach's and Poincaré's evolutionary epistemologies as stemming from their residual tendency to follow Spencer in accepting the completeness of cognitive evolution. It was against the Spencerian version of evolutionally produced cognitive perfection and completeness that Bergson rebelled.[77] The Spencerian evolutionary epistemology had become a quite dominant view by 1890, a fact difficult to believe so absent has been any evolutionary epistemology in the major philosophical discussions of the last fifty years. William James, in 1890, speaks of the pervasive "evolutionary empiricists."[78] Georg Simmel, in 1890, was able to write,

> It has been presumed for some time that human knowing has evolved from the practical needs of preserving and providing for life. The common underlying presupposition is this: there exists objective truth, the content of which is not influenced by the practical needs of the knower. This truth is grasped only because of its utility, correct conceptions being more useful than wrong ones. This view is common to various schools of epistemology, in realism where knowing is an inevitable grasping of an absolute reality, in idealism, where knowing is directed by *a priori* forms of thought.[79]

While accepting a natural selection epistemology, Simmel argues that, for the evolving animal, truth and usefulness are historically one. Anticipating von Uexküll and Bergson, he notes that the phenomenal worlds of animals differ from one to the other, according to the particular aspects of the world they are adapted to and the different sense organs they have.

Pragmatism's relation to natural selection and other evolutionary theories is mixed. In William James's prepragmatism writings, he clearly espoused a natural-selection fallibilism of thought, social evolution, and science, in explicit opposition to Spencer's passive-omniscient Lamarckianism.[80] A vague social-evolutionary orientation appears in his writings on pragmatism, but nowhere as explicit on the issues of importance here. John Dewey's faith in experimentalism was never explicitly related to the variation-and-selective-retention epistemology, and his only reference to natural selection in his book, *The Influence of Darwin on Philosophy*, is in refutation of the argument for God's existence from the wondrous adapted complexity of organisms.[81] In his chapter of that book on the problem of knowledge, no mention of natural selection or trial and error occurs.

Charles Sanders Peirce is profoundly ambivalent in this regard. His concept of truth as "the opinion which is fated to be ultimately agreed to by all who investigate"[82] partakes of the "left-overs" or winnowing model of knowledge which is the particular achievement of the selective retention perspective. Here is another fragment with this flavor:

> . . . it may be conceived, and often is conceived, that induction lends a probability to its conclusion. Now that is not the way in which induction leads to the truth. It lends no definite probability to its conclusion. It is nonsense to talk of the probability of a law, as if we could pick universes out of a grab-bag and find in what proportion of them the law held good. Therefore, such an induction is not valid; for it does not do what it professes to do, namely make its conclusion probable. But yet if it had only professed to do what induction does (namely, to commence a proceeding which must in the long run approximate to the truth), which is infinitely more to the purpose than what it professes, it would have been valid.[83]

Another Peirceian imagery that is quite sympathetic is that of a primeval chaos of chance, within which nodes of order emerged, nodes which grew but never exhausted the chaos, a background of chance and indeterminacy remaining. This imagery is preminiscent of that of Ashby.[84] But the mechanism which is used to explain the emergence is not selective retention, but a mentalistic, anthropomorphic, "tendency to habit" on the part of physical matter:

> . . . a Cosmogonic Philosophy. It would suppose that in the beginning—infinitely remote—there was a chaos of unpersonalized feeling, which being without connection or regularity would properly be without existence. This feeling, sporting here and there in pure arbitrariness, would have started the germ of a generalizing tendency. Its other sportings would be evanescent, but this would have a growing virtue. Thus the tendency to habit would be started; and from this, with the other principles of evolution, all the regularities of the universe would be evolved. At any time, however, an element of pure chance survives and will remain until the world becomes an absolutely perfect, rational, and symmetrical system, in which mind is at last crystallized in the infinitely distant future.[85]

Peirce was thoroughly conversant with the concept of natural selection and recognized it as Darwin's central contribution. Certainly he had in his creative exploration all of the ingredients for a selective retention evolutionary epistemology. Yet, the perspective if ever clearly conceived was also ambivalently rejected, and compatible statements such as those above are few and far between, overshadowed by dissimilar and incompatible elements. Wiener[86] has carefully documented his ambivalence on the issue. In spite of all of his emphasis on evolution, and on the ontological status of chance, Peirce was not a Darwinian evolutionist. Rather he favored the views of both Lamarck and Agassiz, or at least gave them equal status. Wiener is able to quote Peirce as describing Darwin's theory as one which "barely commands scientific respect," and "did not appear at first at all near to being proved, and to a sober mind its case looks less hopeful now [1893] than it did twenty years ago."[87] While later expressing much more Darwinian positions, he hedged by regarding sports (and trial thoughts) as being initiated by lack of environmental fit, and as being formed "not wildly but in ways having some sort of relation to the change needed."[88] Peirce's evolutionism was nostalgic for if not consistently committed to a God-guided evolution:

> . . . a genuine evolutionary philosophy, that is one that makes the principle of growth a primordial element of the universe, is so far from being antagonistic to the idea of a personal creator that it is really inseparable from that idea; while a necessitarian religion is in an altogether false position and is destined to become disintegrated. But a pseudo-evolutionism which enthrones mechanical law is at once scientifically unsatisfactory, as giving no possible hint of how the universe has come about, and hostile to all hopes of personal relations to God.[89]

In connection with such a view, however, he had the important insight that natural laws (and perhaps even God Himself) are evolutionary products and are still evolving.[90]

James Mark Baldwin is known to philosophers today only as the editor of the 1901-1905 *Dictionary of Philosophy* for which Peirce wrote a number of entries. Professionally a psychologist, he is perhaps today better remembered by sociologists of the Cooley tradition, or as a contender for the dubious honor of writing the first social psychology text (that by subtitle and preface) in 1897. Always a vigorous evolutionist, Darwinist-Weismannian and anti-Lamarckian, he turned to epistemology in his later years in his several volumes on *Thought and Things or Genetic Logic*.[91] In 1909 he published casually a brief book on *Darwin and the Humanities*[92] which stands in marked contrast with Dewey's contemporaneous *The Influence of Darwin on Philosophy*[93] for its pervasive use of the natural selection and generalized selective retention theme. In this volume Baldwin summarized more concisely points he had made elsewhere, some of which have been cited above:

> . . . My favorite doctrines, and those in which my larger books have been in some measure original, seem now, when woven together, to have been consciously inspired by the theory of Natural Selection: I need only mention 'Organic Selection,' 'Functional Selection,' 'Social Heredity,' 'Selective Thinking,' 'Experimental Logic,' thoroughgoing 'Naturalism of Method,' etc. Such views as these all illustrate or extend the principle of selection as Darwin conceived it—that is, the principle of survival from varied cases—as over against any vitalistic or formal principle.[94]
>
> . . . Natural selection is in principle the universal law of genetic organization and progress in nature—human nature no less than physical nature.[95]
>
> . . . Summing up our conclusions so far with reference to Darwinism in Psychology we may say:
>
> (1) The individual's learning processes are by a method of functional 'trial and error' which illustrates 'natural' in the form of 'functional selection.'
>
> (2) Such acquisitions, taken jointly with his endowment, give him the chance of survival through 'natural,' in the form of 'organic selection.'
>
> (3) By his learning, he brings himself into the traditions of his group, thus coming into possession of his social heritage, which is the means of his individual survival in the processes of 'social and group selection.'
>
> (4) Thus preserved the individual's endowment or physical heredity is, through variation, directed in intelligent and gregarious lines through 'natural' as 'organic selection.'
>
> (5) Individuals become congenitally either more gregarious or more intelligent for the maintenance of the group life, according as the greater utility attaches to one or the other in the continued operation of these modes of selection.[96]

His distinction between pragmatism and his version of instrumentalism deserves quoting at some length:

> The theory of truth becomes either one of extreme 'Pragmatism' or one

> merely of 'Instrumentalism.'
>
> *Instrumentalism* holds that all truth is tentatively arrived at and experimentally verified. The method of knowledge is the now familiar Darwinian procedure of 'trial and error.' The thinker, whether working in the laboratory with things or among the products of his own imaginative thought, *tries out hypotheses*; and only by trying out hypotheses does he establish truth. The knowledge already possessed is used instrumentally in the form of a hypothesis or conjecture, for the discovery of further facts or truths. This reinstates in the sphere of thinking the method of Darwinian selection.
>
> Here Darwinism gives support to the empiricism of Hume and Mill and forwards the sober British philosophical tradition. And no one illustrates better than Darwin, in his own scientific method, the soberness, caution, and soundness of this procedure.
>
> But a more radical point of view is possible. What is now known as Pragmatism proceeds out from this point. It is pertinent to notice it here, for it offers a link of transition to the philosophical views with which we must briefly concern ourselves.
>
> *Pragmatism* turns instrumentalism into a system of metaphysics. It claims that apart from its tentative instrumental value, its value as guide to life, its value as measured by utility, seen in the consequences of its following out, truth has no further meaning. Not only is all truth selected for its utility, but apart from its utility *it is not truth*. There is no reality then to which truth is still true, whether humanly discovered or not; on the contrary, reality is only the content of the system of beliefs found useful as a guide to life.
>
> I wish to point out that, in such a conclusion, not only is the experimental conception left behind, but the advantages of the Darwinian principle of adjustment to actual situations, physical and social, is lost; and if so interpreted, instrumentalism defeats itself. This clearly appears when we analyze a situation involving trial and error. Trial implies a problematical and alternative result: either the success of the assumption put to trial or its failure. When we ask why this is so, we hit upon the presence of some 'controlling' condition or circumstance in the situation—some stable physical or social fact—whose character renders the hypothesis or suggested solution either adequate or vain, as the case may be. The instrumental idea or thought, then, has its merit in enabling us to find out or locate facts and conditions which are to be allowed for thereafter. These constitute a *control upon knowledge and action*, a system of 'things'.[97]

5. Kant's Categories of Perception and Thought as Evolutionary Products

The evolutionary perspective is of course at odds with any view of an *ipso facto* necessarily valid synthetic a priori. But it provides a perspective under which Kant's categories of thought and intuition can be seen as a descriptive contribution to psychological epistemology. Though we reject Kant's claims of a necessary a priori validity for the categories, we can in evolutionary perspective see the categories as highly edited, much tested presumptions, "validated" only as scientific truth is validated, synthetic a posteriori from the point of view of species-history, synthetic and in several way a priori (but not in terms of necessary validity) from the point of view of an individual organism. Popper makes this point in the following quotation:

The problem 'Which comes first, the hypothesis (H) or the observation (O),' is soluble; as in the problem, 'Which comes first, the hen (H) or the egg (O)'. The reply to the latter is, 'An earlier kind of egg'; to the former, 'An earlier kind of hypothesis'. It is quite true that any particular hypothesis we choose will have been preceded by observations—the observations, for example, which it is designed to explain. But these observations, in their turn, presupposed the adoption of a frame of reference: a frame of expectations: a frame of theories. If they were significant, if they created a need for explanation and thus gave rise to the invention of a hypothesis, it was because they could not be explained within the old theoretical framework, the old horizon of expectations. There is no danger here of an infinite regress. Going back to more and more primitive theories and myths we shall in the end find unconscious, *inborn* expectations.

The theory of inborn *ideas* is absurd, I think; but every organism has inborn *reactions* or *responses*; and among them, responses adapted to impending events. These responses we may describe as 'expectations' without implying that these 'expectations' are conscious. The new-born baby 'expects', in this sense, to be fed (and, one could even argue, to be protected and loved). In view of the close relation between expectation and knowledge we may even speak in quite a reasonable sense of 'inborn knowledge'. This 'knowledge' is not, however, *valid a priori*; an inborn expectation, no matter how strong and specific, may be mistaken. (The newborn child may be abandoned, and starve.)

Thus we are born with expectations; with 'knowledge' which, although not *valid a priori*, is *psychologically or genetically a priori*, i.e. prior to all observational experience. One of the most important of these expectations is the expectation of finding a regularity. It is connected with an inborn propensity to look out for regularities, or with a *need* to *find* regularities, as we may see from the pleasure of the child who satisfies this need.

This 'instinctive' expectation of finding regularities, which is psychologically *a priori*, corresponds very closely to the 'law of causality' which Kant believed to be part of our mental outfit and to be *a priori* valid. One might thus be inclined to say that Kant failed to distinguish between psychologically *a priori* ways of thinking or responding and *a priori* valid beliefs. But I do not think that his mistake was quite as crude as that. For the expectation of finding regularities is not only psychologically *a priori*, but also logically *a priori*: it is logically prior to all observational experience, for it is prior to any recognition of similarities, as we have seen; and all observation involves the recognition of similarities (or dissimilarities). But in spite of being logically *a priori* in this sense the expectation is not valid *a priori*. For it may fail: we can easily construct an environment (it would be a lethal one) which, compared with our ordinary environment, is so chaotic that we completely fail to find regularities. . . .

Thus Kant's reply to Hume came near to being right; for the distinction between an *a priori* valid expectation and one which is both genetically and logically prior to observation, but not *a priori* valid, is really somewhat subtle. But Kant proved too much. In trying to show how knowledge is possible, he proposed a theory which had the unavoidable consequence that our quest for knowledge must necessarily succeed, which is clearly mistaken. When Kant said, "Our intellect does not draw its laws from nature but imposes its laws upon nature", he was right. But in thinking that these laws are necessarily true, or that we necessarily succeed in imposing them upon nature, he was wrong. Nature very often resists quite successfully, forcing us to discard our laws as refuted; but if we live we may try again.

Kant believed that Newton's dynamics was *a priori* valid. (See his *Metaphysical Foundations of Natural Science*, published between the first and the second editions of the *Critique of Pure Reason*.) But if, as he thought, we can explain the validity of Newton's theory by the fact that our intellect imposes its laws upon nature, it follows, I think, that our intellect *must succeed* in this; which makes it hard to understand why *a priori* knowledge such as Newton's should be so hard to come by.[98]

This insight is the earliest and most frequently noted aspect of an evolutionary epistemology, perhaps because it can be achieved from a Lamarckian point of view, as well as from the natural selection model which is absolutely essential to the previous points. Herbert Spencer, a Lamarckian for these purposes, achieved this insight, as Höffding conveniently summarizes:

> With regard to the question of the origin of knowledge Spencer makes front on the one hand against Leibniz and Kant, on the other against Locke and Mill. He quarrels with empiricism for two reasons:—firstly, because it does not see that the matter of experience is always taken up and elaborated in a definite manner, which is determined by the original nature of the individual; secondly, because it is lacking in a criterion of truth. We must assume an original organisation if we are to understand the influence exercised by stimuli on different individuals, and the criterion by means of which alone a proposition can be established is the fact that its opposite would contain a contradiction. In the inborn nature of the individual then, and in the logical principle on which we depend every time we make an inference, we have an *a priori* element; something which cannot be deduced from experience. To this extent Spencer upholds Leibniz and Kant against Locke and Mill; but he does so only as long as he is restricting his considerations to the experience of the individual. *What is a priori for the individual is not so for the race.* For those conditions and forms of knowledge and of feeling which are original in the individual, and hence cannot be derived from his experience, have been transmitted by earlier generations. The forms of thought correspond to the collective and inherited modifications of structure which are latent in every new-born individual, and are gradually developed through his experiences. Their first origin, then, is empirical: the fixed and universal relation of things to one another must, in the course of development, form fixed and universal conjunctions in the organism; by perpetual repetition of absolutely external uniformities there arise in the race necessary forms of knowledge, indissoluble thought associations which express the net results of the experience of perhaps several millions of generations down to the present. The individual cannot sunder a conjunction thus deeply rooted in the organisation of the race; hence, he is born into the world with those psychical connections which form the substrata of "necessary truths" (see *Principles of Psychology*, pp. 208, 216; cf. *First Principles*, p. 53. "Absolute uniformities of experience generate absolute uniformities of thought"). Although Spencer is of opinion that the inductive school went too far when they attempted to arrive at everything by way of induction (for, if we adopt this method, induction itself is left hanging in the air), yet, if he had to choose between Locke and Kant, he would avow himself a disciple of the former; for, *in the long run, Spencer too thinks that all knowledge and all forms of thought spring from experience*. His admission that there is

> something in our mind which is not the product of our own *a posteriori* experience led Max Müller to call him a "thoroughgoing Kantian," to which Spencer replied: "The Evolution-view is completely experiential. It differs from the original view of the experimentalists by containing a great extension of that view.—*But this view of Kant is avowedly and utterly unexperiential.*"[99]
>
> It is of no small interest to notice that John Stuart Mill, who at first demurred at Spencer's evolutionary psychology, afterwards declared himself convinced that mental development takes place not only in the individual but also in the race by means of inherited dispositions. He expressed this modification of his view a year before his death in a letter to Carpenter, the physiologist (quoted in the latter's *Mental Physiology*).[100]

As Wallraff[101] has documented, the demoting of Kant's categories to the level of descriptive rather than prescriptive epistemology began in 1807 with Jacob Fries's effort to interpret the categories as having only a psychological base, as but descriptive of human reason. While such a position was typically accompanied by a thoroughgoing dualism and was purely mentalistic, by 1866 Frederick A. Lange was able to discuss the a priori as aspects of a "physicopsychological" organization of the mind,[102] and to posit, with Mill, the possibility of "erroneous *a priori* knowledge." He also wrote:

> Perhaps some day the basis of the idea of cause may be found in the mechanism of reflex action and sympathetic excitation; we should then have translated Kant's pure reason into physiology, and so made it more easily conceivable.[103]

All that was lacking here was an explicit statement of the kind of validation of such physiological biases which a natural-selection evolution provides. Helmholtz's biological interpretation of the Kantian a priori categories is similar.[104]

Baldwin had the insight in 1902 and earlier:

> As Kant claimed, knowledge is a process of categorizing, and to know a thing is to say that it illustrates or stimulates, or functions as, a category. But a category is a mental habit; that is all a category can be allowed to be—a habit broadly defined as a disposition, whether congenital or acquired, to act upon or to treat, items of any sort in certain general ways. These habits or categories arise either from actual accommodations with 'functional' or some other form of utility selection, or by natural endowment secured by selection from variations.[105]

In the tradition of pragmatism, the categories were seen as but pragmatically useful ways of thinking, usually products of culture history rather than biological evolution,[106] although in espousing such a viewpoint, Wright was able to say in passing:

> In a certain sense, therefore, the distinctions involved in some, at least, of the categories, *viz*., space, time, thing, and person, are present in the sense percepts of animals. . . .It is clear that historically and phylogenetically perceptual elements anticipatory of some of the categories existed prior to the genesis of thought.[107]

Wright's position is extended explicitly by Child[108] who posits both "biotic categories," biological functions shared with animals and of biological survival value, and "sociotic categories" which are cultural products. He says in passing "Since Kant, the term 'category' has primarily referred to the presumably pervasive structures of racial mind."[109]

A great many other scholars have considered some kind of an evolutionary interpretation of Kant's categories, usually very briefly and without citing others. In approximately chronological order these include James, Morgan, Mach, Poincaré, Boltzmann, Fouillé, Cassirer, Shelton, Reichenbach, R. W. Sellars, Uexküll, Meyerson, Northrop, Magnus, Lorenz, Piaget, Waddington, Bertalanffy, Whitrow, Platt, Pepper, Merleau-Ponty, Simpson, W. S. Sellars, Hawkins, Barr, Toulmin, Wartofsky, and Watanabe. Quine, Maxwell, Shimony, Yilmaz, and Stemmer have made much the same point without explicit reference to the Kantian catagories.[110] Of these, many are essentially biologists generalizing into philosophy. This brief quote from Waddington epitomizes their message:

> The faculties by which we arrive at a world view have been selected so as to be, at least, efficient in dealing with other existents. They may, in Kantian terms, not give us direct contact with the thing-in-itself, but they have been moulded by things-in-themselves so as to be competent in coping with them."[111]

Most of the passages cited are very brief, noting the insight only in passing. In marked contrast is the rich exposition provided by Lorenz.

In his essay, "Kant's Doctrine of the *A Priori* in the Light of Contemporary Biology," Lorenz[112] accepts Kant's insight as to some degree of fit between innate categories of thought and the *Ding an sich*. He accepts Kant's claim that without such prior-fitting categories, no one could achieve in his own lifetime the empirical, experiential, knowledge of the world which he does achieve. He accepts in some sense Kant's skepticism as to the form of knowledge. While to Lorenz more than Kant the *Ding an sich* is knowable, it certainly is only known in the knower's categories, not in those of the *Ding an sich* itself. Thus he accepts Kant as psychologist if not as epistemologist. As with all of those we have cited above, from Spencer on, any validity or appropriateness of the categories to the *Ding an sich* is due to their status as a product of an evolution in which the *Ding an sich* has acted in the editorial role of discarding misleading categories.

Lorenz, like Popper[113] recognizes that it was to Kant's great disadvantage to believe Newton's physics perfectly true. When Kant then recognized the a priori human intuitions of space, time, and causality as fitting Newton's physics (which they do to a lesser degree than Kant thought), he had a greater puzzle on his hands than a modern epistemologist has. From our viewpoint, both Newton's laws of dynamics and the intuitive categories of space perception can be seen as but approximations to a later more complete physics (or to the *Ding an sich*).

> The realization that all laws of "pure reason" are based on highly physical or mechanical structures of the human central nervous system which have developed through many eons like any other organ, on the one hand shakes our confidence in the laws of pure reason and on the other hand substantially raises our confidence in them. Kant's statement that the laws of pure reason have absolute validity, nay that every imaginable rational being, even if it were an angel, must obey the same laws of thought, appears as an anthropocentric presumption. Surely the "keyboard" provided by the forms of intuition and categories—Kant himself calls it that—is something definitely located on the physicostructural side of the psychophysical unity of the human organism. . . . But surely these clumsy categorical boxes into which we have to pack our external world "in order to be able to spell them as experiences" (Kant) can claim no autonomous and absolute validity whatsoever. This is certain for us the moment we conceive them as evolutionary adaptations. . . .At the same time, however, the nature of their adaptation shows that the categorical forms of intuition and categories have proved themselves as working hypotheses in the coping of our species with the absolute reality of the environment (in spite of their validity being only approximate and relative). Thus is clarified the paradoxical fact that the laws of "pure reason" which break down at every step in modern theoretical science, nonetheless have stood (and still stand) the test in the practical biological matters of the struggle for the preservation of the species.
>
> The 'dots' produced by the coarse 'screens' used in the reproductions of photographs in our daily papers are satisfactory representations when looked at superficially, but cannot stand closer inspection with a magnifying glass. So, too, the reproductions of the world by our forms of intuition and categories break down as soon as they are required to give a somewhat closer representation of their objects, as in the case in wave mechanics and nuclear physics. All the knowledge an individual can wrest from the empirical reality of the 'physical world-picture' is essentially only a working hypothesis. And, as far as their species-preserving function goes, all those innate structures of the mind which we call 'a priori' are likewise only working hypotheses. Nothing is absolute except that which hides in and behind the phenomena. Nothing that our brain can think has absolute, *a priori* validity in the true sense of the word, not even mathematics with all its laws.[114]

Lorenz portrays for the concepts of space and causality their analogues in water shrew, greylag goose, and man, arguing for each an "objectivity," yet limitedness and imperfection. For a weak microscope, we assume that the homogeneous texture provided at its limit of resolution is a function of those limits, not an attribute of reality. We do this because through more powerful scopes this homogeneity becomes differentiated. By analogy, we extend this assumption even to the most powerful scope. Seeing our human categories of thought and intuition as but the best in such an evolutionary series, even though we might have no better scope to compare it with, generates a parallel skepticism. Actually we do have a better scope, modern physics, which today, at least, if not in Kant's time, provides a much finer grained view of reality.

There is a two-sided message in this literature: there is an "objective" reflection of the *Ding an sich* which, however, does not achieve expression in the *Ding an sich's* own terms. Lorenz, and many of the others, have argued that the mind has been shaped by evolution to fit those aspects of the world with which it deals, just as have other body parts:

> This central nervous apparatus does not prescribe the laws of nature any more than the hoof of the horse prescribes the form of the ground. Just as the hoof of the horse, this central nervous apparatus stumbles over unforeseen changes in its task. But just as the hoof of the horse is adapted to the ground of the steppe which it copes with, so our central nervous apparatus for organizing the image of the world is adapted to the real world with which man has to cope. Just like any organ, this apparatus has attained its expedient species-preserving form through this coping of real with the real during a species history many eons long.[115]

The shape of a horse's hoof certainly expresses "knowledge" of the steppe in a very odd and partial language, and in an end product mixed with "knowledge" of other contingencies. Our visual, tactual, and several modes of scientific knowledge of the steppe are each expressed in quite different languages, but are comparably objective. The hydrodynamics of sea water, plus the ecological value of locomotion, have independently shaped fish, whale, and walrus in a quite similar fashion. Their shapes represent independent discoveries of this same "knowledge," expressed in this case in similar "languages." But the jet-propelled squid reflects the same hydrodynamic principles in a quite different, but perhaps equally "accurate" and "objective" shape. The *Ding an sich* is always known indirectly, always in the language of the knower's posits, be these mutations governing bodily form, or visual percepts, or scientific theories. In this sense it is unknowable. But there is an objectivity in the reflection, however indirect, an objectivity in the selection from innumerable less adequate posits.

6. *Pragmatism, Utilitarianism, and Objectivity*

For both Popper and the present writer the *goal of objectivity* in science is a noble one, and dearly to be cherished. It is in true worship of this goal that we remind ourselves that our current views of reality are partial and imperfect. We recoil at a view of science which recommends we give up the search for ultimate truth and settle for practical computational recipes making no pretense at truly describing a real world. Thus our sentiment is to reject pragmatism, utilitarian nominalism, utilitarian subjectivism, utilitarian conventionalsim, or instrumentalism,[116] in favor of a critical hypothetical realism. Yet our evolutionary epistemology, with its basis in natural selection for survival relevance, may seem to commit us to pragmatism or utilitarianism. Simmel in 1895[117] presents the problem forcibly, as also do Mach and Poincaré.

This profound difference in sentiment deserves much more attention than can be given here, but brief comments from a variety of perspectives may be in order. These are based on the assumption that neither Popper nor the present writer intend to relinquish the goal of objectivity, and must therefore reconcile it with the natural selection epistemology to which that very quest for objective truth has led us.

Where the emphasis on utilitarian selectivity is to counter the epistemic arrogance of a naive or phenomenal realism, we can join it unambivalently. The critical realist has no wish to identify the real with the phenomenally given. Thus the visual and tactual solidity of ordinary objects represents a phenomenal emphasis on the one physical discontinuity most usable by man and his ancestors, to the neglect of other discontinuities identifiable by the probes of modern experimental physics. Perceived solidity is not illusory for its ordinary uses: what it diagnoses is one of the "surfaces" modern physics also describes. But when reified as exclusive, when creating expectations of opaqueness and impermeability to all types of probes, it becomes illusory. The different *Umwelten* of different animals do represent in part the differential utilities of their specific ecological niches, as well as differential limitations. But each of the separate contours diagnosed in these *Umwelten* are also diagnosable by a complete physics, which in addition provides many differentia unused and unperceived by any organism.[118]

Nor do we claim any firmer grounding of the scientific theory and fact of today than do the pragmatists and utilitarians. Indeed, Popper's emphasis on criticism may produce an even greater skepticism as to the realism of present-day science. There is, however, a difference in what it is that is being grounded. Consider a graph of observational points relating the volume of water to its temperature. An extreme punctiform pragmatism or definitional operationism would regard the observations themselves as the scientific truth. A more presumptive pragmatism would fit a least squares curve with minimum parameters to the data, and regard the values of the points on the fitted curve as the scientific facts, thus deviating from some of the original observations. Even at this stage, degrees of pragmatism occur. The departure may be justified purely on the grounds of computational efficiency, or the discrepant observations may be regarded as "errorful," with the anticipation that, were the experiment repeated, the new observations would on the average fall nearer to the "theoretical" values than to the original observations. Most scientific practice is still less pragmatic, more realistic than this: Of all mathematical formulae that fit the data equally well with the same number of parameters, scientists choose that one or those whose parameters can be used in other formulae subsuming other observations. While the search for such parameters may most often be done as a search for physically interpretable parameters, it can also be justified on purely utilitarian grounds. In extending this series, were Popper's position to be classified as a

pragmatism at all it would have to be as pragmatic selection from among formal theories claiming to be universally descriptive of the real world, but not identified as the real world. Even this degree of pragmatism needs to be qualified.

The extremes of pragmatism, definitional operationism, and phenomenalism would equate theory and data in a true epistemological monism. But as elaborated in actual philosophies of science, the dualism of data and theory just described is accepted. Adequately to handle the issues raised in discussions of epistemological monism and dualism[119] we need to expand the framework to an epistemological trinism (trialism, triadism, trimondism) of data, theory, and real world (approximately corresponding to Popper's "second world," "third world," and "first world").[120] The controversial issue is the conceptual inclusion of the real world, defining the problem of knowledge as the fit of data and theory to that real world.

Such a critical realism involves presumptions going beyond the data, needless to say. But since Hume we should have known that nonpresumptive knowledge is impossible. As Petrie[121] has pointed out, most modern epistemologies recognize that scientific beliefs are radically underjustified. The question is thus a matter of which presumptions, not whether or not presumptions. Biological theories of evolution, whether Lamarckian or Darwinian, are profoundly committed to an organism-environment dualism, which when extended into the evolution of sense organ, perceptual and learning functions, becomes a dualism of an organism's knowledge of the environment versus the environment itself. An evolutionary epistemologist is at this level doing "epistemology of the other one,"[122] studying the relationship of an animal's cognitive capacities and the environment they are designed to cognize, both of which the epistemologist knows only in the hypothetical-contingent manner of science. Thus he may study the relationship between the shape of a rat's running pattern ("cognitive map") and the shape of the maze it runs in. Or he may study the polarization of sunlight (using scientific instruments since his own eyes are insensitive to such nuances) and the bee's sensitivity to plane of polarization. At this level he has no hesitancy to include a "real world" concept, even though he may recognize that his own knowledge of that world even with instrumental augmentation is partial and limited in ways analogous to the limitations of the animal whose epistemology he studies. Having thus made the real-world assumption in this part of his evolutionary epistemology, he is not adding an unneeded assumption when he assumes the same predicament for man and science as knowers.

It is true, of course, that in an epistemology of other animals he has independent data on the "knowledge" and "the world to be known," and thus studying the degree of fit involves no tautology. It is true that in extending this "epistemology of the other one" to knowledge of modern physics, no separate information on the world-to-be-known is available with which to compare current physical theory. But this practical limitation does not necessitate abandoning an ontology one is already employing. (This argument is of course only compelling vis-à-vis those of such as Simmel, Mach, and Poincaré, who base their utilitarian nominalism and conventionalism on an evolutionary perspective.)

We can also examine utilitarian specificity versus realism in the evolution of knowing. Consider the spatial knowledge of some primitive locomotor animal, perhaps Konrad Lorenz's [123] water shrew. It may have a thirst space it uses when thirsty, a separate hunger space, a separate space for escape from each predator, a mate-finding space, etc. In its utilitarianism, there is a separate space for every utility. In a higher stage of evolution, the hypothesis has emerged that all these spaces are the same, or overlap. The realistic hypothesis of an all-purpose space has developed. There is abundant evidence that white rat, cat, dog and chimpanzee are at or beyond this stage: that spatial learning achieved in the service of one motive is immediately available for other motives. Along with this goes spatial curiosity, the exploring of novel spaces and objects when all utilitarian motives (thirst, food, sex, safety, etc.) are sated and the exploration has no momentary usefulness. Such disinterested curiosity for "objective," all-possible-purpose spatial knowledge-for-its-own-sake has obvious survival value, even though it may transcend the sum of all specific utilities. Scientific curiosity of course goes beyond the specifically utilitarian to a much greater extent. Survival relevant criteria are rare among the criteria actually used in deciding questions of scientific truth. The science Mach was attempting to epitomize had made most of its crucial selections from among competing theories on the basis of evidence (such as on the phases of the moons of Jupiter) of no contemporary or past utility. And in the history of science, those who took their theories as real, rather than their contemporary conventionalists, have repeatedly emerged in the main stream for future developments.

These several disparate comments scarcely begin the task of relating the critical-realist, natural-selection epistemology to the recurrent issues in the history of the theory of knowledge. Potentially it can provide a dialectic resolution to many old controversies. But spelling out the points of articulation with the main body of epistemological concerns remains for the most part yet to be done.

Summary

This essay has identified Popper as the modern founder and leading advocate of a natural-selection epistemology. The characteristic focus is on the growth of knowledge. The problem of knowledge is so defined that the knowing of other animals than man is included. The variation and selective retention process of evolutionary adaptation is generalized to cover a nested hierarchy of vicarious knowledge processes, including vision, thought, imitation, linguistic instruction, and science.

Historical attention is paid not only to those employing the natural-selection paradigm, but also to the Spencerian-Lamarckian school of evolutionary epistemologists, and to the ubiquitous evolutionary interpretation of the Kantian categories. It is argued that, whereas the evolutionary perspective has often led to a pragmatic, utilitarian conventionalism, it is fully compatible with an advocacy of the goals of realism and objectivity in science.

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NOTES

[1] K. R. Popper, *The Logic of Scientific Discovery* (London: Hutchinson; New York: Basic Books, 1959), p. 42. Hereinafter cited as *L.Sc.D.* Reprinted by permission of the author and publishers.

[2] *L.Sc.D.*, p. 108.

[3] K. R. Popper, *Conjectures and Refutations* (London: Routledge & Kegan Paul; New York: Basic Books, 1963). Hereinafter cited as *C.&R.*

[4] *C.&R.*, p. 46. Reprinted by permission of the author and publishers.

[5] *C.&R.*, p. 51.

[6] *C.&R.*, p. 52. (See also *C.&R.*, pp. 216, 312-13, 383, and *ad passim.*)

[7] For example, *C.&R.*, p. 44.

[8] W. K. Estes, "All-or-None Processes in Learning and Retention," *American Psychologist*, **19** (1964), 16-25; F. Restle, "The Selection of Strategies in Cue Learning," *Psychological Review*, **69** (1962), 329-43; R. C. Atkinson and E. J. Crothers, "A Comparison of Paired-Associate Learning Models Having Different Acquisition and Retention Axioms," *Journal of Mathematical Psychology*, **1** (1964), 285-312.

[9] *L.Sc.D.*, pp. 17-19.

[10] *L.Sc.D.*, p. 22.

[11] Russell has made a similar point in identifying himself with an evolutionary epistemology: "There is another thing which it is important to remember whenever mental concepts are being discussed, and that is our evolutionary continuity with the lower animals. Knowledge, in particular, must not be defined in a manner which assumes an impassable gulf between ourselves and our ancestors who had not the advantage of language," Bertrand Russell, *Human Knowledge: Its Scope and Limits* (New York: Simon and Schuster, 1948), p. 421.

[12] *C.&R.*, p. 216.

[13] *L.Sc.D.*, pp. 278-79.

[14] K. R. Popper, *Of Clouds and Clocks: An Approach to the Problem of Rationality and the Freedom of Man* (St. Louis, Missouri: Washington University, 1966), p. 23. This is the Arthur Holly Compton Memorial Lecture, presented at Washington University on April 21, 1965, and printed as a 38-page booklet; reprinted in K. R. Popper, *Objective Knowledge: An Evolutionary Approach* (Oxford: Clarendon Press; New York: Oxford University Press, 1972). This excerpt reprinted by permission of the author and publishers.

[15] *OCC*, p. 23.

[16] *OCC*, p. 25.

[17] The most complete recent review of this voluminous literature is William Church Wimsatt, "Modern Science and the New Teleology" (unpublished Ph.D. diss., University of Pittsburgh, 1971); and W. C. Wimsatt, "Teleology and the Logical Structure of Function Statements," *Studies in History and Philosophy of Science*, **3**, No. 1 (April, 1972). He recognizes the proper understanding of this problem as inextricably involved with an evolutionary epistemology.

[18] S. Spiegelman, "Differentiation as the Controlled Production of Unique Enzymatic Patterns," *Symposia of the Society for Experimental Biology, II:Growth in Relation to Differentiation and Morphogenesis* (New York: Academic Press, 1948).

[19] H. J. Barr, "Regeneration and Natural Selection," *American Naturalist*, **98** (1964), 183-86.

[20] D. T. Campbell, "Methodological Suggestions from a Comparative Psychology of Knowledge Processes," *Inquiry*, **2** (1959), 152-82: and D. T. Campbell, "Blind Variation and Selective Retention in Creative Thought as in Other Knowledge Processes," *Psychological Review*, **67** (1960), 380-400.

[21] The use of the phrase "inductive achievements" is for convenience in communicating and does not in the least imply advocacy of the Bacon-Hume-Mill explanation of those achievements nor disagreement with Popper's brilliant criticisms of induction.

[22] W. R. Ashby, *Design for a Brain* (New York: John Wiley & Sons, 1952).

[23] The above five paragraphs have been quoted with some rearrangement and transitional modifications from pp. 380 and 381 of Campbell, "Blind Variation" (note 20).

[24] H. S. Jennings, *The Behavior of the Lower Organisms* (New York: Columbia University Press, 1906).

[25] *Design for a Brain* (note 22).

[26] *Ibid.*, p. vi (note 22).

[27] R. J. Pumphrey, "Hearing," *In Symposia of the Society for Experimental Biology, IV: Physiological Mechanism in Animal Behavior* (New York: Academic Press, 1950) pp. 1-18; W. N. Kellogg, "Echo-Ranging in the Porpoise," *Science*, **128** (1958), 982-88; and D. R. Griffin, *Listening in the Dark* (New Haven: Yale University Press, 1958).

[28] D. T. Campbell, "Perception as Substitute Trial and Error," *Psychological Review*, **63** (1956), 331-42.

[29] *Ibid.*, pp. 334-335. Note also the example of left-hand search substituting for right-hand exploration in a blind sorting task.

[30] Beginnings on this problem of pattern matching are to be found in Bertrand Russell's discussion of the "structural postulate," pp. 460-72, and 492, of *Human Knowledge: Its Scope and Limits* (New York: Simon & Schuster, 1948); in Konrad Lorenz, "Gestaltwarnehmung als Quelle wissenschaftliche Erkenntnis," *Zeitschrift für experimentelle und angewandte Psychologie*, **6** (1959), 118-65, translated as "Gestalt Perception as Fundamental to Scientific Knowledge," *General Systems*, **7** (1962), 37-56; and in D. T. Campbell, "Pattern Matching as Essential in Distal Knowing," in *The Psychology of Egon Brunswik*, ed. by K. R. Hammond (New York: Holt, Rinehart & Winston, 1966), pp. 81-106.

[31] The formal analogy between natural selection and trial-and-error learning has been noted by many, including James M. Baldwin, *Mental Development in the Child and Race* (New York: Macmillan, 1900); Samuel Jackson Holmes, *Studies in Animal Behavior* (Boston: Gorham Press, 1916); Ashby, *Design for a Brain;* and J. W. S. Pringle, "On the Parallel Between Learning and Evolution," *Behaviour*, **3** (1951), 175-215.

[32] D. T. Campbell, "Adaptive Behavior from Random Response," *Behavioral Science*, **1** (1956), 105-10.

[33] James M. Baldwin perhaps first proposed the idea. He reprints relevant papers by C. Lloyd Morgan, H. F. Osborn, E. B. Poulton, and himself in *Development and Evolution* (New York: Macmillan, 1902), using the terms "orthoplasy" and "organic selection" to cover the concept.

[33a] In *Objective Knowledge*, pp. 256-80 (note 14).

[34] Wolfgang Köhler, *The Mentality of Apes* (New York: Harcourt, Brace, 1925).

[35] Ernst Mach, "On the Part Played by Accident in Invention and Discovery," *Monist*, **6** (1896), 161-75.

[36] *Ibid.*, p. 171.

[37] *Ibid.*, p. 174.

[38] Henri Poincaré, "Mathematical Creation," in H. Poincaré, *The Foundations of Science* (New York: Science Press, 1913), p. 387.

[39] *Ibid.*, p. 392.

[40] *Ibid.*, p. 393.

[41] *Ibid.*, p. 394.

[42] 1855 is the date of the first edition of Alexander Bain, *The Senses and the Intellect*. The quotations are from the 3d ed. (New York: Appleton, 1874), pp. 593-95.

[43] Stanley Jevons, *The Principles of Science* (London: Macmillan, 1892). (1st ed., 1874; 2d ed., 1877; reprinted with corrections, 1892.)

[44] *Ibid.*, p. 228.

[45] *Ibid.*, p. 577.

[46] Paul Souriau, *Theorie de l'Invention* (Paris: Hachette, 1881), p. 17.

[47] *Ibid.*, p. 43.

[48] *Ibid.*, pp. 114-15.

[49] William James, "Great Men, Great Thoughts, and the Environment," *The Atlantic Monthly*, **46**, No. 276 (October, 1880), 441-59. See also William James, *Principles of Psychology* (New York: Henry Holt, 1890), Vol. II, pp. 617-79.

[50] *Ibid.*, p. 456.

[51] *Ibid.*, p. 457.

[52] "Mathematical Creation" (note 38).

[53] "Part Played by Accident" (note 35).

[54] "Blind Variation" (note 20).

[55] See Appendix I.

[56] See Appendix I.

[57] Herbert A. Simon, *The Sciences of the Artificial* (Cambridge, Mass.: The MIT Press, 1969), p. 95.

[58] A. Newell, J. C. Shaw & H. A. Simon, "Elements of a Theory of Human Problem Solving," *Psychological Review*, **65** (1958), 151-66.

[59] "Blind Variation," pp. 392-95 (note 20).

[60] Newell, Shaw & Simon, "Human Problem Solving" (note 58).

[61] D. O. Hebb, "On the Nature of Fear," *Psychological Review*, **53** (1946), 259-76.

[62] Solomon E. Asch in *Social Psychology* (New York: Prentice-Hall, 1952) has argued the rationality of such imitative or conformant behavior, and the social nature of man's cognition of the world. See also D. T. Campbell, "Conformity in Psychology's Theories of Acquired Behavioral Dispositions," in *Conformity and Deviation*, ed. by I. A. Berg and B. M. Bass (New York: Harper & Row, 1961), pp. 101-42; D. T. Campbell, "Social Attitudes and Other Acquired Behavioral Dispositions," in *Psychology: A Study of a Science*, Vol. 6: *Investigations of Man as Socius*, ed. by S. Koch (New York: McGraw-Hill, 1963), pp. 94-172, and A. Bandura, *Principles of Behavior Modification* (New York: Holt, Rinehart & Winston, 1969).

[63] James M. Baldwin, *Thought and Things, or Genetic Logic* (New York: Macmillan, 1906), Vol. I, p. 169. Popper has also emphasized this, in Sec. 3-V, galleys 5-7 of his unpublished *Postscript*.

[64] R. A. Hinde, ed., *Bird Vocalizations* (Cambridge, England and New York: Cambridge University Press, 1969). See especially the chapters by Lorenz and Immelman.

[65] Karl von Frisch, *Bees, Their Vision, Chemical Sense, and Language* (Ithaca: Cornell University Press, 1950); T. A. Sebeok, ed., *Animal Communication: Techniques of Study and Results of Research* (Bloomington, Ind.: Indiana University Press, 1968); and T. A. Sebeok & A. Ramsay, eds., *Approaches to Animal Communication* (The Hague, Netherlands: Mouton & Company, 1969). Note especially the elegant new confirmation of von Frisch by J. L. Gould, M. Henerey, and M. C. MacLeod, "Communication of Direction by the Honey Bee," *Science*, **169** (1970), 544-54.

[66] The above two paragraphs are condensed from D. T. Campbell, "Ostensive Instances and Entitativity in Language Learning," in *Unity through Diversity*, ed. by N. D. Rizzo (New York: Gordon and Breach, forthcoming in 1973). See also E. R. MacCormac, "Ostensive Instances in Language Learning," *Foundations of Language*, **7** (1971), 199-210. Quine has presented a quite similar view, except for his employment of a passive conditioning learning theory in place of a trial and error of meanings, although his trial and error of "slicings" or abstractions is probably equivalent. See W. V. Quine, *Word and Object* (Cambridge, Mass.: MIT Press, 1960), and especially pp. 26-39 of W. V. Quine, *Ontological Relativity* (New York: Columbia University Press, 1969). Austin's faith that distinctions preserved in ordinary language have as referents distinctions in the world referred to, is justified by a similar model of language evolution.

[67] For a review of this literature, see Margaret Mead, *Continuities in Cultural Evolution* (New Haven: Yale University Press, 1964); and D. T. Campbell, "Variation and Selective Retention in Sociocultural Evolution," in *Social Change in Developing Areas: A Reinterpretation of Evolutionary Theory*, ed. by H. R. Barringer, G. I. Blanksten, and R. W. Mack (Cambridge, Mass.: Schenkman, 1965), pp. 19-49. Perhaps the first to consider social evolution in explicitly natural selection terms was William James, "Great Men, Great Thoughts" (note 49). Louis Rougier has explicitly posited a competition of and a natural selection from among culturally diverse modes of thought in explaining the development of logical and scientific thinking, in *Traité de la Connaissance* (Paris: Gauthier-Villars, 1955), pp. 426-28. See also Pierre Auger (Appendix II).

[68] Joseph Agassi, "Comment: Theoretical Entities Versus Theories," in *Boston Studies in the Philosophy of Science*, ed. by R. S. Cohen and M. W. Wartofsky (Dordrecht, Holland: D. Reidel, 1969), Vol. V.

[69] See Appendix II.

[70] See Appendix III.

[71] W. B. Cannon, *The Way of An Investigator* (New York: W. W. Norton & Co., 1945); R. K. Merton, *Social Theory and Social Structure* (Glencoe: Free Press, 1949).

[72] K. R. Popper, *Postscript*, unpublished, galleys 5-7, Secs. 3-V and 3-IX.

[73] S. E. Toulmin, "The Evolutionary Development of Natural Science," *American Scientist*, **55** (1967), 456-71. See also S. E. Toulmin, *Foresight and Understanding: An Inquiry Into the Aims of Science* (Bloomington, Indiana: Indiana University Press, 1961); S. E. Toulmin, "Neuroscience and Human Understanding," in *The Neurosciences*, ed. by Frank Schmitt (New York: Rockefeller University Press, 1968); S. E. Toulmin, *Human Understanding*, Vol. I: *The Evolution of Collective Understanding* (Princeton, N. J.: Princeton University Press, 1972).

[74] *Foresight and Understanding* (note 73); T. S. Kuhn, *The Structure of Scientific Revolutions* (Chicago: University of Chicago Press, 1962).

[75] Robert Ackermann, *The Philosophy of Science* (New York: Pegasus, 1970).

[76] Milič Čapek, "The Development of Reichenbach's Epistemology," *Review of Metaphysics*, **11** (1957), 42-67; Milič Čapek, "La Théorie Biologique de la Connaissance chez Bergson et sa Signification Actuelle," *Revue de Metaphysique et de Morale* (April-June, 1959), 194-211; and Milič Čapek, "Ernst Mach's Biological Theory of Knowledge," *Synthese*, **18** (1968), 171-91, reprinted in *Boston Studies in the Philosophy of Science*, ed. by R. S. Cohen and M. W. Wartofsky (Dordrecht, Holland: D. Reidel, 1969), Vol. V, pp. 400-21.

[77] Bergson also rejected the Darwinian blind mutation and natural selection model of cognitive evolution. However, his emphasis on the utility-perspectival, partial, oversimplified, nature of human cognition, and its inappropriateness when extended into the subatomic and galactic areas is in agreement with the natural selection epistemology advocated here ("La Théorie Biologique"). That Mach and Poincaré were explicitly natural-selectionist rather than Lamarckian both in their perspective on cognitive evolution and in their treatment of creative thought indicates the need for further analysis. Čapek's attribution to Mach of Spencer's belief in the completeness and perfection of the evolutionary process is contradicted by this quotation from Mach's contemporary, Boltzmann, "Mach himself has shown in a most ingenious way that no theory is either absolutely true or absolutely false, and that, moreover, every theory is constantly being improved just as are organisms as described by Darwin." *Populäre Schriften*, p. 339 (Appendix II).

[78] *Principles of Psychology*, p. 617 (note 49).

[79] Georg Simmel, "Über eine Beziehung der Selectionslehre zur Erkenntnis-theorie," *Archiv für systematische Philosophie*, **1**, No. 1 (1895), 34-45. The present writer has had the benefit of access to two unpublished papers, the first is Herman Tennessen, "Brief Summary of Georg Simmel's Evolutionary Epistemology," June, 1968, being an abstract of Herman Tennessen "Georg Simmel's tillemping av selecksjonslaeren pa erkjennelsesteorier," in *Filosofiske Problemer* (Oslo: Norwegian University Press, 1955), pp. 23-30. The second is a preliminary translation of Simmel's paper by Irene L. Jerison. Simmel does not, in fact, cite Spencer, nor any other on this point.

[80] *Principles of Psychology* and "Great Men, Great Thoughts" (note 49).

[81] John Dewey, *The Influence of Darwin on Philosophy* (New York: Henry Holt & Co., 1910; Bloomington: Indiana University Press, 1965), pp. 11-12.

[82] *Collected Papers of Charles Sanders Peirce*, ed. by Charles Hartshorne and Paul Weiss (Cambridge, Mass.: Harvard University Press, 1931-58), 5.407. (All references to Peirce in this paper follow the standard practice of designating volume and paragraph in the *Collected Papers*.) Also quoted in Manley Thompson, *The Pragmatic Philosophy of C. S. Peirce* (Chicago: University of Chicago Press, 1953), p. 83, and in Philip P. Wiener, *Evolution and the Founders of Pragmatism* (Cambridge, Mass.: Harvard University Press, 1949), p. 93.

[83] *Collected Papers*, 2.780.

[84] *Design for a Brain* (note 26).

[85] *Collected Papers*, 6.33. See also 5.436, 6.200, 6.262, 6.606, 6.611.

[86] *Founders of Pragmatism*, Chap. 4, pp. 70-96 (note 82).

[87] *Ibid.*, p. 77.

[88] *Ibid.*, pp. 87-88.

[89] *Collected Papers*, 6.157, original date 1892.

[90] Wiener, *Founders of Pragmatism*, pp. 94-95 (note 82); Peirce, *Collected Papers*, 1.348.

[91] James M. Baldwin, *Thought and Things, A Study of the Development and Meaning of Thought, or Genetic Logic*, Volume I: *Functional Logic or Genetic Theory of Knowledge;* Volume II: *Experimental Logic or Genetic Theory of Thought;* Volume III: *Genetic Epistemology* (London: Swan Sonnenschein [in Muirhead's Library of Philosophy]; New York: Macmillan, 1906, 1908, 1911). If these volumes left any impact at all, it was in the French tradition out of which Jean Piaget's recent work on genetic epistemology emerges.

[92] James M. Baldwin, *Darwin and the Humanities* (Baltimore: Review Publishing Co., 1909; London: Allen & Unwin, 1910).

[93] *Influence of Darwin* (note 81).

[94] *Darwin and Humanities*, p. viii (note 92). Reprinted by permission of the American Psychological Association.

[95] *Ibid.*, p. ix.

[96] *Ibid.*, pp. 32-33.

[97] *Ibid.*, pp. 68-73.

[98] *C.&R.*, pp. 47-48.

[99] Harold Höffding, *A History of Modern Philosophy* (London: Macmillan, 1900; New York: Dover, 1955), Vol. II, pp. 475-76.

[100] *Ibid.*, pp. 457-58.

[101] Charles F. Wallraff, *Philosophical Theory and Psychological Fact* (Tucson: University of Arizona Press, 1961), pp. 10-11.

[102] *Ibid.*, p. 11; Frederick Albert Lange, *The History of Materialism* (New York: Humanities Press, 1950), Vol. 2, p. 193. (Reprinting of a translation first published in 1890.)

[103] *History of Materialism*, p. 211 (note 102).

[104] Čapek, "Mach's Theory of Knowledge" (note 76).

[105] The quotation is from James M. Baldwin, *Development and Evolution* (New York: Macmillan, 1902), p. 309. See also his *Mental Development* (Macmillan, 1900), and *Darwin and the Humanities* (note 97).

[106] E.g., William James, *Pragmatism* (New York: Longmans-Green, 1907), pp. 170, 182, 193. This is also Rougier's position, *Traité de la Connaissance* (note 67). Marx Wartofsky also emphasizes primarily the social evolution of the Kantian a priori, in "Metaphysics as Heuristic for Science," in *Boston Studies in the Philosophy of Science*, ed. by R. S. Cohen and M. W. Wartofsky (Dordrecht, Holland: D. Reidel, 1968), Vol. III, pp. 164-70.

[107] William K. Wright, "The Genesis of the Categories," *The Journal of Philosophy, Psychology and Scientific Methods*, **10** (1913), 645-57, esp. 646.

[108] Arthur Child, "On the Theory of the Categories," *Philosophy and Phenomenological Research*, **7** (1946), 316-35.

[109] Child, "Theory of Categories," p. 320.

[110] See Appendix IV.

[111] "Evolution and Epistemology" (Appendix IV).

[112] "Kants Lehre vom apriorischen" (Appendix IV).

[113] *C.&R.*, p. 48, quoted above note 98. See also Hans Reichenbach, as reported by Čapek, "Reichenbach's Epistemology" (note 76).

[114] Lorenz, "Kants Lehre vom apriorischen," pp. 103-4, translation pp. 26-27 (Appendix IV). Reprinted by permission of the author.

[115] *Ibid.*, pp. 98-99, translation p. 25 (Appendix IV).

[116] Note that James M. Baldwin as quoted above, *Darwin and the Humanities*, pp. 68-73 (note 97), uses the term instrumentalism in a unique way, in making the very point against pragmatism being made here.

[117] "Beziehung der Selectionslehre" (note 79).

[118] von Bertalanffy, "Relativity of Categories" (Appendix IV).

[119] A. O. Lovejoy, *The Revolt Against Dualism* (La Salle, Ill.: Open Court, 1930); W. Köhler, *The Place of Value in a World of Facts* (New York: Liveright, 1938).

[120] K. R. Popper, "Epistemology without a Knowing Subject," in *Logic, Methodology, and Philosophy of Sciences*, ed. by B. van Rootselaar and J. E. Staal (Amsterdam: North-Holland, 1968), Vol. III, pp. 333-73; K. R. Popper, "On the Theory of the Objective Mind," *Akten des XIV internationalen Kongresses für Philosophie*, **1** (Vienna, 1968), 25-53. Both are reprinted in *Objective Knowledge* (note 14), pp. 106-52 and 153-90.

[121] H. G. Petrie, "The Logical Effects of Theory on Observational Categories and Methodology," duplicated (Northwestern University, June 20, 1969).

[122] D. T. Campbell, "Methodological Suggestions from a Comparative Psychology of Knowledge Processes," *Inquiry*, **2** (1959), 157; D. T. Campbell, "A Phenomenology of the Other One: Corrigible, Hypothetical, and Critical," in *Human Action*, ed. by T. Mischel (New York: Academic Press, 1969), pp. 41-69.

[123] "Kants Lehre vom apriorischen" (Appendix IV).

Appendix I: Trial-Error and Natural-Selection Models for Creative Thought

Alexander Bain, *The Senses and the Intellect*, 3d ed. (New York: Appleton, 1874), pp. 593-95. (1st ed., 1855.)

Stanley Jevons, *The Principles of Science* (London: Macmillan Co., 1892). (1st ed., 1874.)

William James, "Great Men, Great Thoughts, and the Environment," *The Atlantic Monthly*, **46**, No. 276 (October, 1880), 441-59.

Paul Souriau, *Theorie de l'Invention* (Paris: Hachette, 1881).

Ernst Mach, "On the Part Played by Accident in Invention and Discovery," *Monist*, **6** (1896), 161-75.

James M. Baldwin, *Mental Development in the Child and the Race* (New York: Macmillan, 1900).

A. Fouillé, *L'Evolutionisme des Idées-Forces* (Paris: Alcan, 1906), pp. 276-77. (Note that his emphasis on *conscience* as providing a goal-directed "artificial selection," in contrast with the aimless natural selection, deserves separate treatment.)

Henri Poincaré, "Mathematical Creation," in H. Poincaré, *The Foundations of Science* (New York: Science Press, 1913), pp. 383-94. (First published in 1908.)

W. B. Pillsbury, *The Psychology of Reasoning* (New York: Appleton-Century-Crofts, 1910).

E. Rignano, *The Psychology of Reasoning* (New York: Harcourt, Brace, 1923). (French ed. 1920.)

R. S. Woodworth, *Psychology* (New York: Henry Holt and Co., 1921).

L. L. Thurstone, *The Nature of Intelligence* (New York: Harcourt, Brace, 1924).

E. C. Tolman, "A Behavioristic Theory of Ideas," *Psychological Review*, **33** (1926), 352-69.

John L. Lowes, *The Road to Xanadu* (New York: Houghton Mifflin, 1927; New York: Vintage Books, 1959).

C. L. Hull, "Knowledge and Purpose as Habit Mechanisms," *Psychological Review*, **37** (1930), 511-25.

K. F. Muenzinger, "Vicarious Trial and Error at a Point of Choice: I. A General Survey of Its Relation to Learning Efficiency," *Journal of Genetic Psychology*, **53** (1938), 75-86.

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