Without Miracles

9. The Development and Functioning of Thought

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But the same term [thinking] is also used when thinking does become an achievement, that is, when it is productive. This happens when it changes our mental environment by solving problems which this environment offers. . . . The range of such achievements is tremendous. It extends from the solution of very simple problems in everyday life to veritable mental revolutions such as sometimes occur in the minds of great scientists and may then affect the lives of human beings forever afterward.

--Wolfgang Köhler[1]

One striking characteristic of our species is the degree to which we use thought processes to solve the many problems we encounter daily. Whether planning a vacation, balancing a checkbook, debugging a computer program, or making a scientific discovery that will ultimately affect the lives of millions of people, much more than just overt behavior is involved. The behaviorist theories of Pavlov, Thorndike, Watson, and Skinner dominated American psychology during much of the first two-thirds of the twentieth century. Some psychologists, however, particularly in Europe, continued their attempts to understand the development and functioning of the animal and human minds, including the development and functioning of thought itself. When behaviorism finally began to wane in the second half of this century, there began what has been called a cognitive revolution as the disciplines of psychology, linguistics, anthropology, philosophy, neuroscience, and computer science joined forces in an attempt to shed light on the mysterious and powerful inner workings of the brain.[2]

But if the process of thinking is adapted to solving the problems posed by the physical and social environments of a person or animal, this presents another example of a puzzle of fit that demands explanation. How is it that merely thinking about a problem can lead to its solution? If a solution is not evident when a problem is first encountered, what does thinking do to find one? And how is it that an adult is able to perceive things and solve problems that he could not as a child? These are the types of puzzles of fit that we will now consider.

The Problem of Problem Solving: Köhlers Chimps

At the same time that Thorndike and Watson were using a behavioral approach to animal (including human) learning that shunned any consideration of mental operations (see chapter 7), three German psychologists--Max Wertheimer, Franz Koffka, and Wolfgang Köhler--were taking a quite different approach to understanding animal learning. Of these three, Köhler (1887-1967) is probably the best known for his study of chimpanzees between 1913 and 1920 on Tenerife, one of the Canary Islands off the coast of Spain.[3]

Köhler devised a number of tasks to examine the problem-solving abilities of his chimps. One task involved suspending a banana high out of reach so that the only way to obtain it was to stack one or more boxes underneath on which the animal could climb and grab the fruit. A second task involved putting a stick inside the chimp's cage and a banana outside, so that the banana could be had by using the stick to pull it within reach. A variation of this required inserting one end of a rod into the end of another to make a tool of sufficient length. In the *Umweg* ("detour") task, a desired object was placed behind bars or a window, making it necessary for the animal first to move away from the object to circumnavigate the barrier between it and the object. Köhler used this last task not only with his chimpanzees but also with dogs, chickens, and children of various ages.

The chimpanzees demonstrated varying degrees of success on these problems. Almost all of them were able to solve the single box-stacking problem, and one was able to stack up to four boxes. They all eventually discovered how to use a stick to pull bananas within reach of the cage, but only two hit on the solution of joining two rods together to make a longer one. And whereas chimps (as well as children and dogs) were able to solve various *Umweg* tasks intelligently, the chickens were successful only when their frantic movements brought them by chance to a spot where they could see the detour around the obstacle.

The intelligent behavior demonstrated by the chimpanzees appeared very different from the gradual, trial-and-error solutions to the puzzle-box problems demonstrated by Thorndike's dogs and cats as described in chapter 7. Indeed, the apes would often pause and appear to think about the problem before suddenly coming up with a solution that was then immediately implemented as "a single continuous occurrence, a unity, as it were, in space as in time . . . as one continuous run, without a second's stop, right up to the objective."[4] It was this pause preceding a rapidly implemented solution to a problem that Köhler saw as an indication of truly "intelligent behavior," as opposed to the "mechanized behavior" demonstrated by the chickens in his *Umweg* task, and the cats and rats in Thorndike's and Watson's puzzle boxes and mazes.

Köhler believed that for his chimps to solve these and other problems intelligently, they had to be able to visualize the problem mentally in a new way. That is, a perceptual reorganization had to take place that brought to the chimp's attention certain relationships and possibilities that the chimp had not noticed before. Seeing a stick lying in the cage and a banana outside the cage will not suggest a solution unless a certain relationship is perceived between them, namely, that the stick can be used as a means to rake in the fruit. Indeed, Köhler found that such problems were often solved more quickly if the stick was placed where it and the banana could be seen at the same time. Once this new vision was mentally realized, the chimp then only had to act on it to solve the problem. This process of perceptual reorganization followed by a recognition that a particular reorganization provides a solution was referred to by Köhler as "insight" (*Einsicht* in German) and is also known as the aha! phenomenon.

But calling such behavior insightful does little to help us understand the thought processes involved, as indeed Köhler admitted in his later years:

Insight is insight into relations that emerge when certain parts of a situation are inspected. . . . In the solution of a problem . . . we suddenly become aware of new relations, but these new relations appear only after we have mentally changed, amplified, or restructured the given material.[5]

As an example of the role of insight in human problem solving, Köhler offers a problem similar to the one shown in figure 9.1. Here, the task is to determine the length of line *a* relative to some aspect of the circle. Some readers may see the answer to this problem almost immediately, but others may not. The latter readers would profit from taking time to try to solve the problem before reading further, while at the same time noting the thoughts that occur while wrestling with the problem.

The answer is that the length of line *a* is the same as the radius of the circle. This becomes obvious when the other diagonal of the rectangle is imagined. This other diagonal is found to extend from the center of the circle to its circumference, and therefore is equal to the circle's radius. Since the two diagonals of a rectangle are equal in length, line *a* must also be equal to the radius. Köhler continues his discussion of the role of insight making reference to this problem:

> Thus, when we dealt with the diagonal within a certain rectangle constructed within a circle . . . everything was, of course, clear once we had drawn the second diagonal, which then proved to be identical to the radius of the circle. But why, after inspecting the situation as first given, did we ever think of drawing new lines, and particularly that special line, the second diagonal? . . . After it had happened, we understood, of course that this was the right procedure. But we could not realize this until the grouping had been done. What, then made us introduce this particular structuring or grouping at a time when we could not yet be aware of its consequences?[6]

Here he appears to be admitting that insight cannot explain problem solving, but is rather a consequence of first producing and then selecting a useful perceptual reorganization. But how can we (or our brain) know which reorganization will lead to the solution? Indeed, if we knew in advance how to solve it, we wouldn't have had the problem in the first place! This, of course, is just another instance of Meno's dilemma described in chapter 6.

One possible solution would be to postulate that the brain produces a series of varied perceptual reorganizations until one is produced that is recognized as leading to the solution and therefore selected. If you were unable to solve the problem presented in figure 9.1 immediately, you may recall experiencing just such a series of variations in your perception of it. Although such thoughts would no doubt be constrained by your previous knowledge of geometry and similar problems,[7] they would in an important sense be *blind* variations in that you could not know beforehand which particular perceptual organization would lead to the solution. But this is not the reasoning that Köhler uses. Instead, he concludes his discussion of problem solving by simply restating the problem, this time using the word "revolutions" to refer to perceptual reorganizations:

> Why do such revolutions which occur in certain brains tend to be the right revolutions? . . . [W]hy do brain processes tend to produce perceptual organizations of remarkable clearness of structure? At least this part of nature, the human brain, seems to operate in a most selective fashion. It is the *direction* of its operations which is truly remarkable.[8]

This last sentence suggests that Köhler believed that some degree of foresight is involved since the brain seems to know in what direction the solution of a new problem lies. But of course this conclusion simply begs the question of the origin of this "directional" knowledge.

Köhler and his Gestalt psychology colleagues made many important contributions to our knowledge of animal and human perception and problem solving. They provided much in the way of evidence and arguments that the problem-solving behavior of animals and humans could not be easily accounted for by the concepts of stimulus, response, and reward of American behaviorism that was then so popular. The contrast between the two schools of thought was noticed by British mathematician and philosopher Bertrand Russell, who observed that "animals studied by Americans rush about frantically, with an incredible display of hustle and pep, and at last achieve the desired result by chance [whereas those] observed by Germans sit still and think, and at last evolve the solution out of their inner consciousness."[9] However, in their haste to discard behaviorist, "mechanistic" explanations of problem solving, the Germans may have also unfortunately discarded the solution to the puzzle of problem solving, a solution hinted at by Russell's use of the phrase "evolve the solution out of their inner consciousness."

Piagets Genetic Epistemology

Another European who had an even greater impact on the study of thought processes was psychologist Jean Piaget (1896-1980). Prolific in research and writing from the age of 10 years until shortly before his death,[10] Piaget began his career as a biologist specializing in mollusks such as the snails inhabiting the lakes of his native Switzerland. However, a job in Paris administering intelligence tests to children sparked a life-long interest in the development of mental abilities and knowledge. Piaget called this study "genetic epistemology," the word *genetic* in this case referring not to the genes but rather to a conceptualization of the development of thought as a process of internally guided cognitive growth.

Piaget employed an ingenious mélange of questioning and simple experiments that led to a number of fascinating discoveries concerning children's thought and cognitive development. For example, he would spread two rows of eight coins each in front of a young child so that each coin in the bottom row was directly beneath the corresponding coin in the top row. When asked which row had more coins, the child would correctly answer that each row was the same. But if the distance between each coin in the bottom row was increased (without adding any coins) while the child watched so that the bottom row became longer, the child would now answer that the bottom row had more coins than the top row.

Piaget also demonstrated that children were able to solve certain concrete, hands-on tasks before they could solve the same problem at a more abstract, logical, and verbal level. So, for example, given a short red stick (1) and a longer green one (2), and then shown the same green one (2) and a still longer yellow one (3), a nine-year-old would have no difficulty in stating that the yellow stick (3) was longer than the red stick (1). However, when told and not shown that stick 1 is shorter than 2, and stick 2 is in turn shorter than 3 (that is, $1 < 2$ and $2 < 3$), and asked whether stick 1 or 3 was longer, the same child would have great difficulty arriving at the correct answer that 3 is longer than 1 ($1 < 3$).

These and many other observations and experiments by Piaget clearly demonstrated that the thought of the young child is different not only *in degree* from that of the adult, but also *in kind*, and he concluded that each child goes through an invariant series of cognitive stages, with each stage requiring a major overhaul of the preceding one.[11] For example, for a young infant, an object exists only if it can be presently seen, felt, heard, or smelled. At this age, removing a desired object from view usually results in the infant abandoning all efforts to find and obtain it. But the child soon develops "object permanence," so that she is now able to seek and find objects that were hidden while she was watching. From a Piagetian perspective, the developing child is like a little scientist who is constantly developing and testing new theories about the world, rejecting old theories when a new one proves better suited to making sense of the world and meeting her needs.

But if, as Piaget demonstrated, the child's thought becomes better and better adapted to the world, we must ask ourselves how this increase in fit is possible. Piaget was very clear in his rejection of both providential and instructionist views. His rejection of a genetic form of providentialism can be seen in his criticisms of the view that some innate, preformed knowledge must exist that cannot be explained by a process of cognitive growth. And his rejection of instruction is made clear in his criticisms of empiricist psychological theories that attempt to account for knowledge growth as a process of taking in and internalizing sensory experience. Instead, he considered mental growth to be a *constructive* process that cannot be accounted for by innately provided knowledge or instructive sensory experience, either working separately or in combination.

It might reasonably be expected that Piaget's realization of the inadequacy of providential (innatist) and instructionist (empiricist) accounts of mental development, coupled with his early training as a biologist, would have led him quite naturally to a selectionist view of the development of thought. He rejected the theory of Darwinian evolution,[12] however, reasoning that:

> Either chance and selection can explain everything or else behavior is the motor of evolution. The choice is between an alarming waste in the shape of multitudinous and fruitless trials preceding any success no matter how modest, and a dynamics with an internal logic deriving from those general characteristics of organization and self-regulation peculiar to all living beings.[13]

But what exactly does Piaget mean by his appeal to behavior as the "motor of evolution" guided by "an internal logic" and "general characteristics of organization and self-regulation peculiar to all living beings"; and where did this logic, organization, and self-organization come from? Unfortunately, he provided no clear, compelling answers to these questions, leaving himself vulnerable, as we will see, to the innatist arguments of Noam Chomsky.

Having rejected Darwin's selectionist theory of evolution, it should not be surprising that Piaget saw little role for variation and selection in his theory of cognitive development. But this put him in a curious predicament in essentially rejecting all three major explanations for the growth in adapted complexity of human thought processes: providence (both divine and genetic), instruction, and selection. He described an alternative theory of development using terms such as "assimilation," "accommodation," "equilibration," "reflective abstraction," and "autoregulation"--terms many psychologists and students of psychology have struggled to understand.[14]

Despite anti-Darwinian sentiments, the major themes of his theory can be understood from a selectionist perspective. According to Piaget, the two major ways in which children (as well as adults) interact with their world are through assimilation and accommodation. Assimilation refers to an incorporation of some sensory experience into a preexisting thought structure or schema (we will ignore for now the origin of this preexisting schema). For example, a child having seen sparrows and blackbirds and able to recognize them as members of the category "bird" would likely assimilate the sighting of a starling into this same category. The child might also attempt to assimilate the first observed butterfly into the bird schema since it shares certain similarities with other members of this category. However, calling a butterfly a bird would very likely result in a correction by an adult or older child, "That's not a bird, it's a butterfly!" This would then require accommodation of the child's thought so that butterflies and birds would be treated as different types of objects, each with its own label and distinguishing characteristics.[15]

But an adult cannot directly instruct the child with respect to the conventional use of words such as *bird* and *butterfly*. This means that a father cannot simply transmit the meanings of new words to his child. Indeed, the child only knows that some sort of error has been made and that, according to his father, the current object in view is not a bird but a butterfly. But the father's remark does not tell the child *why* it is a butterfly and not a bird. Is it because it is yellow and the other flying organisms he has seen are brown and black (but then what of canaries?)? Is it because it stops to sip nectar from flowers, and the other flying creatures do not (but then what of hummingbirds?)? Or is it because birds have only been seen in the afternoon and it is now morning (but then what of the birds that get the worms?)? Clearly, the child must make some sort of guess as to how to modify his bird schema and create a new butterfly one. This guess may well be initially wrong, but by continuing to use and test additional guesses, the child will eventually come to the same notions of bird and butterfly that are shared by most adults of the speech community. (More will be said about the child's acquisition of vocabulary in chapter 11.)

The Providential Innatism of Chomsky and Fodor

The person who probably did more than any other to change the course of psychology in the second half of the twentieth century was not even a psychologist. In 1959 Chomsky published a devastating review of Skinner's book *Verbal Behavior* that is often cited as marking the beginning of the cognitive revolution in psychology. The review legitimized the study of thought and cognitive processes after half a century of behaviorist domination in North America that had banned all such attempts as unscientific and subjective.

In this and other writings, Chomsky convincingly maintained that language behavior could not be accounted for by reinforcement of certain responses under particular stimulus conditions. Rather, any attempt to understand how we can acquire, use, and understand language must take into consideration that most of language consists of novel utterances that the speaker has never heard or uttered before. Thus the only way a person with a finite brain can produce and understand a potentially infinite number of novel sentences is by using an internal mental grammar of abstract, generative rules and principles.

Chomsky was fascinated by how children are able to master their native language so quickly and with so little difficulty despite both their informal, unsystematic exposure to language and its staggering complexity. To account for this remarkable feat, he came to the conclusion that much conceptual and linguistic knowledge is innate. As he states:

> It seems that the child approaches the task of acquiring a language with a rich conceptual framework already in place and also with a rich system of assumptions about sound structure and the structure of more complex utterances. These constitute the parts of our knowledge that come "from the original hand of nature," in Hume's phrase. They constitute part of the human biological endowment, to be awakened by experience and to be sharpened and enriched in the course of the child's interactions with the human and material world.[16]

Chomsky revolutionized the field of linguistics in pursuit of his ambitious goal to find a system of innate, universal grammar that would make the task of aquiring language as easy as possible while still leaving enough leeway for a child to acquire any of the 5000 or so of the world's languages fate may have chosen as his mother tongue.

But Chomsky's powerful intellect and formidable powers of rhetoric were not to be limited to attacks on the instructionist theories of the behaviorists. In a series of lively debates with Piaget, he and philosopher Jerry Fodor attacked Piaget's constructivist theory of knowledge as well, and it is here that Piaget's reluctance to embrace a selectionist theory of cognitive development caused him considerable difficulty in countering these assaults. The innatist position and the basic argument against the constructivism of Piaget is perhaps best summed up by Fodor:

> There literally isn't such a thing as the notion of learning a conceptual system richer than the one that one already has; we simply have no idea of what it would be like to get from a conceptually impoverished to a conceptually richer system by anything like a process of learning.[17]

How could Piaget have best countered these arguments? If we substitute the words "less adaptedly complex" and "more adaptedly complex" or "less fit" and "more fit" for Fodor's "conceptually impoverished" and "conceptually richer," respectively, we can see how an evolutionary process involving cumulative cognitive variation and selection could in principle provide a selectionist answer to Chomsky and Fodor, thus allowing Piaget to reject their innatist views of mental development for a constructionist one. Piaget's failure to do so and his vain attempt to provide a Lamarckian explanation of how an organism's experience can be transmitted to its genome[18] contributed to Chomsky's looking very much the winner in the published version of this debate.[19]

The issues concerning language, thought, and cognitive development are exceedingly complex and therefore risk being seriously oversimplified and misunderstood in such a cursory presentation. I tolerate this risk only because I believe that the core of this dispute involving three of this century's most influential thinkers about thought can be understood as an avoidable consequence of the rejection of the creative potential of Darwinian evolution, and failure to appreciate how a within-organism selectionist mechanism could in principle account for the construction of knowledge and thought without requiring either the preformed, innate knowledge of Chomsky and Fodor or the convoluted constructive mechanisms of Piaget.

Chomsky and Fodor offered a genetically providential explanation for the remarkable fit between the language and concepts of the child and that of his environment. As with all providential theories, however, theirs encounters serious difficulties when one inquires as to the origin of the provided knowledge. If they accepted that biological evolution could in principle lead to the emergence of this complex and adapted knowledge, they would be undermining their basic position that simpler systems cannot on their own give rise to more adaptedly complex ones. The two may be right in their assertion that all human conceptual knowledge is innate. But their basic argument that such knowledge *must* be innate because new, more complex, adapted systems cannot emerge from preexisting, less complex adapted systems (as clearly happens in the process of adaptive organic evolution) is obviously flawed. The evidence discussed in chapter 4 that the mammalian brain undergoes a type of adaptive evolution during the lifetime of the animal by way of variation and selection of synapses provides an important additional reason to doubt Chomsky and Fodor's innatist views.

Piaget also rejected an evolutionary account of thought and knowledge as well as the providential innatism of Chomsky and Fodor. This left him in a particularly difficult position to account for the child's construction of knowledge and advanced thought processes, and led him to flirt with Lamarckian explanations for cognitive development. (We will return to Chomsky and Fodor and these issues in our discussion of human language in chapter 11.)

Early Selectionist Theories of Thought

Regardless of the rejection of Darwinian explanations of cognitive development and thought by Piaget, Chomsky, and Fodor during the second half of this century, selectionist views of knowledge, thought, creativity, and invention have a long and impressive history. Since proponents of such views include some of the most insightful and influential psychologists, scientists, and philosophers of their day, it will be well worth our time to become acquainted with some of these views.

Alexander Bain (1818-1903), a Scottish philosopher and psychologist, emphasized the great number of trials required for scientific discoveries and the importance of the potential discoverer's commitment and fascination with the subject of his problem:

> The invention of Daguerre [of the first photographic process] illustrates--by a modern instance--the probable method whereby some of the most ancient inventions were arrived at. The inventions of

> the scarlet dye, of glass, of soap, or gunpowder, could have come only by accident; but the accident, in most of them, would probably fall into the hands of men engaged in numerous trials upon the materials involved. Intense application--"days of watching, nights of waking,"--went with ancient discoveries as well as with modern. In the historical instances, we know as much. The mental absorption of Archimedes is a proverb.[20]
>
> The number of trials necessary to arrive at a new construction, is commonly so great, that, without something of an affection, or fascination, for the subject, one grows weary of the task. The patient thought of the naturalist desirous of rising to new classifications, grows out of his liking for the subject, which makes it to him a sweet morsel rolled under the tongue, and gives an enjoyment even to fruitless endeavours.[21]

English economist and logician W. Stanley Jevons (1835-1882), in his rejection of Sir Francis Bacon's instructionist view of science (to be discussed in chapter 10), also offered a selectionist account of the human mind's ability to provide new insights into its environment.

> 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.
>
> 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.[22]

Regardless of Jevons's selectionist insight, it surely cannot be the case that "the truest theories involve suppositions which are inconceivable," but rather that suppositions that would be inconceivable if based firmly on already achieved knowledge are conceivable for selectionist, guess-based thought mechanisms of Jevons's "teeming brain."

Chauncey Wright (1830-1875), an American mathematician and philosopher of the pragmatic school, had an important impact on American philosophy, primarily through his interactions with William James and Charles Sanders Peirce. The social event of Wright's life was his trip to England in 1872 to visit Charles Darwin, and Darwin was sufficiently impressed with Wright's defense of Darwinism that he reprinted and distributed at his own expense one of Wright's essays entitled "The Genesis of Species." Of most relevance to the current chapter is that Wright also applied Darwin's principles of variation and selection to an attempt to understand the functioning of the human mind:

> In further illustration of the range of the explanation afforded by the principle of Natural Selection. . . we may instance an application of it to the more special psychological problem of the development of the individual mind by its own experiences. . . . Here, then, is a close analogy, at least, to those fundamental facts of the organic world on which the law of Natural Selection is based; the facts, namely, of the "rapid increase of organisms," limited only by "the conditions of existence," and by

> competition in that "struggle for existence" which results in the "survival of the fittest." As the tendency to an unlimited increase in existing organisms is held in check only by those conditions of their existence which are chiefly comprised in the like tendencies of other organisms to unlimited increase, and is thus maintained (so long as external conditions remain unchanged) in an unvarying balance of life; and as this balance adjusts itself to slowly changing external conditions, so, in the history of the individual mind, beliefs which sprang spontaneously from simple and single experiences, and from a naturally unlimited tendency to generalization, are held mutually in check, and in their harmony represent the properly balanced experiences and knowledges of the mind, and by adaptive changes are kept in accordance with changing external conditions, or with the varying total results in the memory of special experiences.[23]

This extract reveals Wright to be no master of lucid English prose, but the use of the very Darwinian ideas of variation, competition, and selection are evident here. Instead of a Darwinian competition among organisms, Wright describes a mental competition among beliefs, with both other current beliefs and the environment acting to eliminate those less fit and leaving the better-adapted ones.

Already described in chapter 8 as having an important insight into the purposeful nature of the behavior of humans and other animals, William James was very much influenced by Darwinian ideas in his formulation of psychological theories concerning the development and function of thought.[24]

> . . . new conceptions, emotions, and active tendencies which evolve are originally *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. . . .
>
> The conception of the [newly discovered 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.[25]

Frenchman Paul Souriau in 1881 mentioned the central role played by chance in invention:

> 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 on chance.
>
> 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 frivolous, 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. . . .
>
> 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.[26]

American psychologist James Mark Baldwin (1861-1934) is of particular interest since he spent considerable time in France and is believed to have had an influence on the psychological theorizing of Piaget. Unlike Piaget, however, he believed that Darwinian views of cumulative variation and selection could be applied fruitfully not only to psychology but also to ethics, logic, philosophy, religion, judgment, and logic. In a volume published in 1909 to mark the fiftieth anniversary of the publication of Darwin's *Origin*, Baldwin treated all these subjects and expressed the hope that his book would also stimulate Darwinian thinking in other fields of the humanities such as anthropology, philology, political science, and literary criticism. Baldwin thought the selectionist theory of adaptive evolution had potential application to all these disciplines, but as a psychologist he was particularly interested in its application to human thought and intelligence:

> And how far the method of law called by Darwin "natural selection" goes, what its range really is, we are now beginning to see in its varied applications in the sciences of life and mind. It seems to be--unless future investigations set positive limits to its application--a universal principle; for the intelligence itself, in its procedure of tentative experimentation, or "trial and error," appears to operate in accordance with it.[27]

Austrian physicist and philosopher Ernst Mach, who lived from 1838 to 1916, and whose name remains synonymous with the speed of sound, was intrigued with the function of thought, particularly as it related to the advancement of science. When he assumed the new professorship in "The History and Theory of Inductive Sciences" created for him at the University of Vienna in 1895, he offered a clearly selectionist account of scientific and artistic creativity:

> The disclosure of new provinces of facts before unknown can only be brought about by accidental circumstances. . . .
>
> 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 highflown 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 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.[28]

Particularly significant in Mach's explanation of creativity is the notion of a cumulative selection process that gradually leads to fit "thoughts, melodies, or harmonies," but that nevertheless may appear both to the thinker and observer as an inexplicably sudden and insightful creative act.

Renowned French mathematician Henri Poincaré (1854-1912) wrote an essay on mathematical creativity derived from his own creative experiences in which he emphasized the blind recombination of elements and the selection of those products in the unconscious mind according to criteria of harmony, beauty, and usefulness:

> 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. . . .
>
> 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. . . .
>
> Perhaps we ought to seek explanations 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 . . . where they are enclosed, as would, for example, a swarm of gnats. . . . Then their mutual impacts may produce new combinations. . . .
>
> In the subliminal self . . . 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 combination.[29]

It is noteworthy that although these eight individuals worked in quite divergent fields of inquiry, from psychology for Bain to mathematics for Poincaré, they all were in remarkable agreement with respect to their selectionist perspective on human thought. Central to them all is the idea that useful thoughts (beliefs, ideas) can be found only if the thinker produces a large number of varied and blind guesses. Thus, Bain is convinced that "the inventions of the scarlet dye, of glass, of soap, or gunpowder, could have come only by accident." Jevons argued that "fertility of imagination and abundance of guesses at truth are among the first requisites of discovery." Wright wrote of the "unlimited, expansive power of repetition" of memories, experiences, and beliefs. James explained how "new conceptions, emotions, and active tendencies which evolve are originally *produced* in the shape of random images, fancies, accidental outbirths of spontaneous variation in the functional activity of the excessively unstable human brain." For Souriau "there is no way to begin except at random." Mach wrote about "the teeming, swelling host of fancies which a free and highflown imagination calls forth." And Poincaré described how "among the great numbers of combinations blindly formed by the subliminal self, almost all are without interest and without utility."

But of course simply churning out a great variety of thoughts (commonly referred to as brainstorming today) cannot in itself lead to useful ones. For this, as in biological evolution, the problem at hand must somehow be involved in selecting and retaining the useful thoughts while eliminating the useless ones. Thus Wright wrote of the "`struggle for existence' which results in the `survival of the fittest'" ideas. James remarked that thoughts are something 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." Souriau appeared to make a very clear analogy to natural selection in stating that "by a kind of artificial selection, we can in addition substantially perfect our thought and make it more and more logical" and that "of all the ideas which present themselves to our mind, we note only those which have some value and can be utilized in reasoning." Mach noted that "from the teeming, swelling host of fancies which a free and highflown imagination calls forth, suddenly that particular form arises to the light which harmonizes perfectly with the ruling idea, mood, or design." And Poincaré found that of the multitude of ideas which come to mind as one struggles with a problem, "only certain ones are harmonious, and, consequently, at once useful and beautiful."

But whereas these individuals all shared what we might call the selectionist insight concerning thought, they did not provide particularly strong logical or philosophical arguments, or cogent historical or psychological evidence to support their theories. In addition, the rise of behaviorism in the United States at the beginning of the twentieth century made it very unpopular to base any psychological theory on subjective and unobservable mental processes. Scientists such as Köhler, Piaget, and Chomsky who swam against the behaviorist tide and rejected trial-and-error theories of overt behavior also rejected trial-and-error theories of thought. It may well be for these reasons that selectionist views of thinking practically disappeared during the first half of the twentieth century and did not make a comeback until the second half.

Thought as Substitute Trial and Error: Campbells Hierarchy of Knowledge Processes

It is largely due to the work of American psychologist Donald T. Campbell (born in 1916 and now professor emeritus at Lehigh University in Bethlehem, Pennsylvania) that a general selection theory of thought is known (and contested) today. Campbell has three major accomplishments to his credit in this regard. First, he documented the discovery and use of selectionist theories of thought by philosophers, psychologists, mathematicians, and other scientists since the time of Darwin.[30] Second, over a period of more than 35 years he provided strong arguments that the Darwinian process of blind variation and selective retention underlies all achievements of fit, including the fit of our perceptions to the world they represent, the fit of our thoughts and mental processes to the real-world problems we confront and successfully solve, and the fit of our scientific theories and predictions to the universe they describe. Finally, he provided a hierarchy of knowledge processes in an attempt to show how the evolution and ontogeny of all forms of knowledge can be accounted for within a general selectionist framework.

Campbell lays out four basic premises which provide the foundation for his 11-level hierarchy of knowledge processes.[31]

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

Here we see the centerpiece of Campbell's epistemology in the bold claim that blind variation and selection is the only natural (that is, nonmiraculous) explanation for any increase in adapted complexity, for any increase in fit of one system with respect to another.

> 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.

While the first point may appear to be a dogmatic and unsupportable claim, the second point is quite different in that it posits mechanisms for variation, selection, and retention. Thus, Campbell makes the testable prediction that for any system that shows an increase in adapted complexity over time, careful examination will reveal mechanistic processes of variation, selection, and retention underlying this adaptation. In this regard it is of interest to note that Darwin believed that these three processes were responsible for biological evolution. He could argue convincingly only for mechanisms of selection ("survival of the fittest"), however, since he had no knowledge of the mechanisms of either genetic variation or retention. If Campbell's conjectures are correct, we would expect that research into natural and artificial adaptive systems would eventually yield concrete evidence of the underlying mechanisms of variation, selection, and retention. This indeed turned out to be the case in the fields of immunology and neurology, as we already saw in chapters 4 and 5. Chapters 14 and 15 address how the same appears true in computer science and molecular design.

> 3. The many processes which shortcut a more full blind-variation-and-selective-retention process are 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.

This concept of shortcut or vicarious[32] processes that substitute for longer, more tedious, and more costly blind variation and selective retention is central to Campbell's hierarchy and so merits further elaboration. Let us take a blind man as an example. If placed in an unfamiliar house, the blind man can exit only by moving to and searching the walls with his hands until he finds the door leading outside. In the process he may well trip on furniture and other objects, or tumble down a flight of stairs. This is obviously very costly in terms of energy and time, and a dangerous way to solve his problem of exiting the house.

But now imagine that the man is given a long cane that he can use to probe the space around him more efficiently and safely. Note that although he is not in any sense less blind than he was without the cane, he is in much better circumstances since by tapping his cane he can substitute for the more costly and dangerous manual groping he would have to do without the cane. The cane has a rather limited range of effectiveness, however, and it is still necessary for the man to move about the room as he taps.

Let us now suppose that the man is equipped with an infrared sensing device that, by emitting and timing the arrival of reflected infrared waves, can compute the distance of an object and present this information by producing an audible tone that covaries in pitch with this distance so that close objects sound higher than more distant ones. Now he is able to obtain information from the entire room without having to move around it at all. Slight dips in frequency would indicate the corners of the room, with a dramatic dip indicating an open window, doorway, or stairway. Notice that such a system begins to resemble vision in its operation. A hostage who is transported to a strange house while blindfolded and then manages to remove his blindfold is in much the same situation as the blind man with the infrared device. Initially, the hostage has no idea where a window or door might be, and can only look around "blindly" until he finds something that might provide a means of escape.

But can it make any sense to refer to vision as blind? We certainly don't just look anywhere and everywhere in using vision to solve problems. We normally don't search for doors on the ceiling or floor. Unlike the drunkard, we don't look for our lost keys under a streetlight if we know we dropped them in a dark part of the street. When faced with a problem, we don't normally just try *anything*. To do so would be very inefficient and make it quite unlikely that we would find the solution to our problem. That is, we use *constraints* (or *restraints*) to solve problems and make new discoveries.

Undoubtedly such constraints can be very helpful in finding solutions to problems and discovering new knowledge, and they may be necessary if we want to be able to find a solution in a reasonable length of time. An experienced mechanic will not check the muffler of a car if the motor will not start, and will not examine the fuel injection system if the car runs well but makes excessive noise. Experience permits the physician to eliminate many possible causes of disease based on the patient's symptoms. Knowledge based on previous similar experiences can constrain the search space of possible solutions that make useless variations *less* likely and therefore potentially useful ones *more* likely. But we must keep in mind three important things concerning constraints. First, insofar as they are useful and therefore fit the problem at hand, *this fit of the constraints themselves must be explained*. Thus if we wish to avoid providential or instructionist explanations for the fit, the existence of constraints must be explained as the result of previous blind variation and selection.

Second, no matter how useful they may be, constraints alone cannot account for solutions to new problems. As argued by Campbell:

> Intelligent variations require an explanation for how these variations or hypotheses came to be wise-in-advance. That most hypotheses *are* wise, I have no doubt. As such, they reflect already achieved knowledge or, at very least, wise restrictions on the search space. Such wisdom does not, however, explain further advances in knowledge. That hypotheses, even if not wise, are far from random, I agree. But wise or stupid, *restraints* on the search space do not explain novel solutions. [33]

Third, there is no guarantee that constraints that proved useful in the past will continue to do so in the future. Indeed, in many respects progress in science can be seen as the sweeping away of old constraints that are no longer considered valid. The early conception of the universe revolving about the earth at its center constrained astronomy in ways that were originally useful, but this constraint was completely rejected by Copernicus and later astronomers. The everyday ideas that light is unaffected by gravity and mass is unaffected by heat and velocity were constraints important in Newton's day, but were discarded by Einstein and later physicists. And the constraints provided by religious doctrine that viewed the design of all creatures as unchallengeable proof of the handiwork of a supreme creator were dramatically overturned by Darwin.

Now that we have examined the basic ideas motivating Campbell's thoroughly selectionist view of knowledge, we are in a better position to examine his proposed hierarchy of knowledge processes (table 9.1) and see how and where thought fits in. The first level is genetic adaptation. This, of course, refers to the processes of cumulative genetic variation and selection that underlie biological evolution. We already saw in chapters 2 and 3 how biological evolution can lead to remarkable fit in both the structures and behavior of organisms. Genetic adaptation has a rather serious limitation, however; it normally takes a considerable amount of time and thus cannot provide adaptive changes during the lifetime of any individual organism.

But as we have already considered in our discussion of learning and perceptual control theory in chapters 7 and 8, changing environmental conditions and unpredictable disturbances continually present new problems and make it advantageous, if not necessary, for an organism to be able to learn and adapt during its own lifetime, that is, ontogenetically. Accordingly, the second level of Campbell's hierarchy is the simplest conceptualization of such an ability, that is, *nonmnemonic*[34] *problem solving*. We had an example of nonmnemonic problem solving in our brief encounter with *E. coli* in the previous chapter. Recall that the bacterium can only either swim in a relatively straight line or tumble about randomly until it sets off in a new random direction. If it senses that it is swimming in the right direction, toward food or away from danger, it will continue to move in that direction. If, however, it senses that it is not getting closer to food or farther from danger, it will tumble for a while and then set off in a new direction. So whereas *E. coli* is able to solve the problem of finding food and avoiding danger, and can do this in complex, changing environments, it cannot profit from experience. As it begins to tumble, it has no memory of the direction in which it was last traveling and therefore is just as likely to set off in this same direction as any other. Of course, it is much more likely to choose a new bearing, since there are many more new directions than the single old one.

Campbell's third level is *vicarious locomotor devices*. As we learned with regard to the blind man, exploring one's environment with a remote sensory system has important advantages over locomotion and direct physical contact. Particularly striking examples of this are the sophisticated echolocation systems of bats, porpoises, and cave birds. Without such a sensory system, a bat could only make its way out of a dark cave by repeatedly flying into the walls of the cave until it eventually discovered the entrance. Its echolocation system makes such costly (in terms of time and energy) and dangerous fumblings unnecessary, as it provides a type of substitute locomotor device so that the bat can find its way into the open faster, with less energy, and more safety than by flying into the cave walls. Campbell admits that it is difficult for most people to conceptualize vision itself as a vicarious locomotor device that operates using blind variation and selection. He maintains that this is, however, the case, as suggested by the blind man with the infrared distance detector.

We now move to Campbell's fourth and fifth levels, *habit* and *instinct*. As described in chapter 3, instinct is generally understood as resulting from the evolutionary selection of organisms with useful behaviors, and habit is typically considered to result from behavioral consequences of the experiences of an individual organism. As shown in chapter 7, however, serious problems arise if instinct and habit are considered as being linked to specific behaviors, since behavior must remain constantly adaptive (and therefore variable) for it to be useful in achieving the goals of an organism living in an unpredictable and disturbance-rich environment. We can nonetheless keep the essential character of Campbell's thought if we reconsider instinct to be the result of the selection of organisms with useful (fit) perceptual control systems, and substitute for habit the reorganization of these control systems that an organism accomplishes to solve problems.

As we move into the next level of Campbell's hierarchy we finally meet the principal concern of this chapter--thought. The sixth level, *visually supported thought*, is:

> the dominant form of insightful problem solving in animals, e.g., as described by Köhler [and] 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.[35]

To provide an example of visually supported human thought, imagine attempting to rearrange the furniture in your living room to accommodate an upright piano. In looking over the room as currently furnished, you could readily imagine other possible arrangements. You might think, "The sofa could be moved from the back wall to under the window, freeing up wall space for the piano, and the two chairs currently under the window could be moved to the empty corner." Of course, this plan may not prove to be the most acceptable if you then realize that the piano would block access to the built-in bookcase, but other arrangements could easily be imagined as you observe the room's current configuration and contents. Once a decision is made, however, you could implement it directly, without having to try out physically each of the arrangements you considered and then rejected in your thinking.

As mentioned by Campbell above and as we considered earlier, this appears to be the type of thought process used by Köhler's chimpanzees to solve various problems. However, the chimps did not seem capable of Campbell's seventh level of knowledge processes, that is, *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.[36]

To extend our example, imagine that you are now contemplating the purchase of a piano in the dealer's showroom and imagining how it could be incorporated into your living room. Since you are not in your living room and therefore cannot see it, you must rely on your memory of it to determine where the piano could be put. This memory represents the knowledge you must have to solve the problem of piano placement. In this case, knowledge may well exist as some type of mental image, although this is most likely only one of many forms that it can take (language being another to be discussed later in this chapter). As such, it substitutes for the visual perception of the room, which in turn substitutes for locomotion-based examination of the room and its contents. The comments of Bain, Baldwin, James, Jevons, Mach, and Poincaré given earlier would all appear to apply to this type of mnemonically supported thought. Another way to conceptualize both visually and mnemonically supported thought is to consider them as forms of *simulation.* (The current use of computers for simulation will be examined in chapter 13.)

Campbell's eighth level comprises *socially vicarious exploration* and *observational learning and imitation*. We now consider the social aspects of knowledge processes and how other organisms can greatly facilitate an individual's acquisition of knowledge. In socially vicarious exploration

> 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. . . . [Observational learning and imitation] 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.[37]

But even in the case of learning by imitation, Campbell is careful to discount an instruction-based explanation in stating that

> 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 pointed out by Baldwin, 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.[38]

A particularly striking characteristic of human knowledge processes is the role that language plays in thought and the acquisition of knowledge. Although Campbell puts language at the ninth level, he notes that it overlaps with the two previous levels, since it is generally believed to be the most important tool for both mnemonically supported thought and socially dependent knowledge processes.

He notes that through our use of language "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."[39] He further observes:

> From the social-functional point of view, it is quite appropriate to speak of the "language" of the 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.[40]

Of course, the richness and expressive power of human language far surpass the one-track communication of bees, but the major function remains the same. Language allows us to gain knowledge through someone else's experiences and thoughts, insofar as they can be expressed in language. Yet even our knowledge of language, as in the meanings of words, must proceed by trial and error. As we considered in our discussion of Piaget, concepts such as bird and butterfly, and hence the meanings of their associated words, cannot be transmitted from one person to another, but must be created and tested by each individual. We can therefore never be certain that what we understand by a certain word is the same meaning understood by someone else. "Just as certain knowledge is never achieved in science, so certain equivalence of word meanings is never achieved in the iterative trial and error meanings in language learning."[41] (We will return to the puzzle of language learning and use in chapter 11.)

But despite the tentative, unjustified nature of the meanings shared in language, language has clearly played a major role in the cultural and technological evolution of our species. Through the relatively recent expression of written language, we can learn from the experiences and thoughts of those who lived centuries ago, and share this knowledge and our own discoveries with generations yet to come. The *cultural cumulation* greatly facilitated by language is the tenth level of knowledge processes in which "there are a variety of variation and selective retention processes leading to advances or changes in technology and culture."[42] And as the most impressive example of the accumulation of human knowledge, science is Campbell's eleventh level.

The grand breadth of this hierarchy of knowledge processes clearly goes beyond the scope of a chapter dealing primarily with thought. It is presented here in some detail since Campbell's radically selectionist epistemology is perhaps unique in its outright rejection of all providential and instructionist accounts of knowledge acquisition at all levels, from biological evolution and human perception and thought through the progress of science. Wherever Campbell sees evidence of fit, he is quick to point out how the mechanisms of variation and selection provide the only explanation for such fit that does not require the assistance of a supernatural provider or the workings of unfathomable mechanisms of passive sensory instruction.

Campbell has offered philosophical, logical, historical, and anecdotal reasons for considering thinking as the blind variation and selection of thought trials for over 35 years. But he has not undertaken psychological research to provide evidence for his claims and has admitted that it is very difficult to test them through scientific studies of thinking and problem solving. This may be one reason why Campbell's hierarchy has not had very much impact on mainstream psychological theory. This may well change, however, as the selectionist discoveries in immunology and neuroscience, together with the many practical uses to which selection theory is now being put (and to be discussed in part IV), become more widely known and appreciated.

[1]Köhler (1969, pp. 133-134).

[2]See Gardner (1987) for an account of the history of the cognitive revolution.

[3]Parts of the following account of Köhler's research are based on Boakes (1984, pp. 184-196). Koffka, Wertheimer, and Köhler were the leading proponents of what is called Gestalt psychology (*Gestalt* is a German word most often translated as "form"). Gestalt psychologists stress the importance of the integrity and wholeness of perception, and note that our perceptions are different from the sum of the parts of the stimuli that give rise to them. Thus ** ** ** is seen quite differently from *** ***, although both configurations are made up of six asterisks.

[4]Köhler (1925, p. 17).

[5]Köhler (1969, pp. 152, 153).

[6]Köhler (1969, pp. 153, 154).

[7]For example, you may have tried to calculate the length of line *l* using your knowledge of Pythagoras's theorem, which states that the square of the diagonal of a right triangle is equal to the sum of the square of the two bases.

[8]Köhler (1969, p. 164).

[9]Russell (1927; quoted in Boakes, 1984, p. 202).

[10]Piaget was author or coauthor of more than 30 books.

[11]Piaget's four major stages of human mental development are the sensorimotor stage, the preoperational stage, concrete operations, and formal operations.

[12]See Vidal et al. (1983) and Vonèche (1985) for attempts to understand the reasons for Piaget's rejection of Darwinian theory. These include his religious beliefs (at one time he considered entering the ministry), his socialization into a Lamarckian form of biology, and his aversion to the wasteful picture of nature painted by the Darwinian concepts of blind chance and the struggle for survival.

[13]Piaget (1976; quoted in Vidal et al., 1983, p. 87).

[14] The difficulties encountered by students and scholars attempting to come to grips with Piaget's account of cognitive growth can be appreciated by pondering the following quotation:

> We still have to look for the reason why constructions required by the formation of reason become progressively necessary when each one begins by various trials that are partly episodic and that contain, until rather late, an important component of irrational thought (non-conservations, errors of reversibility, insufficient control over negations, and so on). The hypothesis naturally will be that this increasing necessity arises from autoregulation and has a counterpart with the increasing, parallel equilibration of cognitive structures. Necessity then proceeds from their "interlocking." (Piaget, quoted in Piattelli-Palmarini, 1980, p. 31)

[15] Shortly after I wrote this paragraph, I was seated in a dentist's waiting room when a woman and her young daughter between one and two years of age sat down beside me. The girl had picked up a children's book that contained within its cardboard pages various types of surfaces to explore by touching. She touched one of these surfaces and said, "Wet!" Thereupon her mother immediately replied, "That's not wet, it's *sticky*."

[16]Chomsky (1988b, p. 34).

[17]Fodor in Piattelli-Palmarini (1980, p. 149).

[18]Piaget's Lamarckian tendencies are clearly revealed in his notion of the "phenocopy," a term he used to describe the inheritance of acquired characteristics that he believed to have observed in the freshwater snail *Limnea*. See Danchin (1980) for a refutation of Piaget's interpretation of the evolution of the *Limnea* and an alternative that is consistent with Darwinian theory.

[19]Piattelli-Palmarini (1980).

[20]Bain (1868, p. 596). See Roberts (1989) for a more up-to-date account of accidental scientific discoveries.

[21]Bain (1868, p. 593).

[22]Jevons (1874; quoted in Campbell, 1974a, p. 428).

[23]Wright (1877/1971, pp. 115-116).

[24]Although James claimed that his application of evolutionary principles to hu-man thought was original, he was almost certainly influenced by discussions with Wright and knowledge of Wright's essays (see O'Hara, 1994).

[25]James (1880, pp. 456, 457).

[26]Souriau (1881; quoted in Campbell, 1974a, p. 429).

[27]Baldwin (1889, p. 83).

[28]Mach (1896; quoted in Campbell, 1974a, p. 427).

[29]Poincaré (1913; quoted in Campbell, 1974a, pp. 427-428).

[30]See Campbell (1974a).

[31]The following four numbered paragraphs are taken from Campbell (1974a, p. 421).

[32]The word *vicarious* refers to something being performed or experienced in a substitute fashion for another, in the same sense that a *vicar* is considered an earthly substitute and representative of Christ or God.

[33]Campbell (1990, p. 9).

[34]*Mnemonic* refers to memory. Thus, memory plays no role in nonmnemonic problem solving.

[35]Campbell (1974a, p. 427).

[36]Campbell (1974a, p. 472).

[37]Campbell (1974a, p. 431).

[38]Campbell (1974a, p. 432). Note that this account of imitation is quite consistent with the perceptual control theory account of behavior as described in chapter 8, with the criterion image serving as the reference level with the reorganization of control systems leading to the child's perception (of his song) eventually matching the reference level of the remembered song.

[39]Campbell (1974a, p. 432).

[40]Campbell (1974a, p. 432).

[41]Campbell (1974a, p. 433).

[42]Campbell (1974a, p. 434).