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TARGET ARTICLE

Creativity as Blind Variation and Selective Retention: Is the Creative Process Darwinian?

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Darwinism provides not only a theory of biological evolution but also supplies a more generic process applicable to many phenomena in the behavioral sciences. Among these applications is the blind-variation and selective-retention model of creativity proposed by Campbell (1960). Research over the past 4 decades lends even more support to Campbell's model. This support is indicated by reviewing the experimental, psychometric, and historiometric literature on creativity. Then 4 major objections to the Darwinian model are examined (sociocultural determinism, individual volition, human rationality, and domain expertise). The article concludes by speculating whether the Darwinian model may actually subsume all alternative theories of creativity as special cases of the larger framework.

The theory of biological evolution by natural selection is widely considered to be one of the most powerful explanatory frameworks in the biological and behavioral sciences (Cziko, 1995; Dennett, 1995). Ever since the theory was jointly presented by Charles Darwin and Alfred Wallace in 1858—and especially since it was more fully developed in Darwin's *Origin of Species* in the following year—the "Darwinian" explanatory system has come to have repercussions for any discipline concerned with organisms, including all fields dealing with human behavior. Although these extensions and applications of Darwinism are extremely diverse, they can be grouped into two types of theoretical interpretations (cf. Bradie, 1995).

In the primary type of Darwinism, the original theoretical system of Darwin and Wallace was elaborated, expanded, and sometimes redefined so as to encompass increasingly more aspects of biological evolution. In Darwin's own day, these developments included the introduction of the concept of sexual selection as well as the explicit extension of the theory to explain the evolution of *Homo sapiens.* Later, of course, the theory merged with Mendelian genetics to produce Neo-Darwinism or the "Modern Synthesis" (Huxley, 1942). This led to the development of population genetics, in which the theory could claim a mathematical foundation (Fisher, 1930). Even more than a century after the *Origin of Species*, this primary Darwinism would see its explanatory scope and predictive power greatly enlarged, especially after evolutionary theory became grounded in molecular biology. From the standpoint of the behavioral sciences, the most notable development (even if perhaps the most controversial one) was the advent of sociobiology (Wilson, 1975), especially the emergence of sociobiological explanations of sexual behavior and altruism (e.g., Buss, 1995). Of course, not all developments of the theory were equally successful, and the jury is still out on some of the most recent extensions of primary Darwinian theory.

The secondary type of Darwinism is almost as important. Darwin and Wallace did more than provide a mechanism that could account for the evolution of life forms. They also provided a model that could be generalized to all developmental or historical processes that freely generate variations that are later selected, retained, and reproduced (Cziko, 1995; Dennett, 1995). The earliest such metaphorical application of any importance appeared in the form of the now discredited social Darwinism, but later examples of secondary Darwinism have enjoyed more scientific creditability. In the biological sciences, these applications include explanations of antibody formation (Söderqvist, 1994) and neuronal growth (e.g., Edelman, 1987). In the behavioral sciences, secondary Darwinism is visible in domains as diverse as Skinnerian operant conditioning (Skinner, 1938), cultural evolution (Cavalli-Sforza & Feldman, 1981), and evolutionary epistemology (Campbell, 1974a).[1] The latter development is especially fascinating, because evolutionary epistemologists argue that the cultural history of scientific knowledge is governed by the same principles that guide the natural history of biological adaptations (Dawkins, 1986). Ideational variations first proliferate, and then a subset of them are selected for preservation by the sociocultural system. The very history of Darwinism illustrates this process. The basic ideas first promulgated by Darwin and Wallace were extended to large numbers of intellectual variations, some primary and others secondary. Those that seemed to "fit the facts"—or at least avoided extinction by Popperian falsification (Popper, 1959)—were the ones to pass down to subsequent generations (see also Hull, 1988; Shrader, 1980; Toulmin, 1981).

Another application of secondary Darwinism is closely related to evolutionary epistemology. If the evolution of knowledge is based on the generation of variations, then we must ask where those variations come from. The obvious answer is that these variations come from a human mind, but how does the individual arrive at new ideas in the first place? How do human beings create variations? One perfectly good Darwinian explanation would be that the variations themselves arise from a cognitive variation-selection process that occurs within the individual brain. Not surprisingly, one of the champions of this Darwinian theory of creativity was Donald Campbell (1960), who was also among the most stalwart proponents of evolutionary epistemology (e.g., Campbell, 1974a). More than three decades have elapsed since Campbell first outlined his model of the creative process, and a lot of research on creativity and problem solving has appeared in the interim. Yet it is my view that Campbell's (1960) classic article still provides the best framework for a comprehensive theory of creativity.

Because the latter belief is far from representing the majority view of those who study creative behavior, I wish to devote this article to the extension and elaboration of the Darwinian explanation of creativity.[2] I begin by recapitulating Campbell's (1960) argument. I then bring this argument up to date by incorporating the key developments in the scientific study of creative behavior. I next briefly examine three of the more conspicuous objections to a Darwinian viewpoint.

Darwinian Creativity

According to the selectionist theory of biological evolution, there exists a mechanism for producing abundant and diverse variations. Although Darwin and Wallace were not specific about the mechanisms, in the modern version of the theory this variation is produced by two means, recombination of old genes and the provision of new genes through mutation. Those inherited and mutant genes that confer enhanced ability to survive and reproduce in their possessors will be those that will have higher odds of appearing in the next generation. This evaluation of "reproductive fitness" is executed by the environment according to how well a particular genotype is adapted to available food resources, physical hazards, potential predators and parasites, and prospective mates. The most provocative feature of the Darwinian theory is not the selection process per se, but rather the variation process. The mechanisms responsible for genetic recombination and mutation typically operate in ignorance of the future reproductive fitness of the organism. In sexually reproducing diploid species, for example, a single recessive but deleterious gene will appear in the fertilized ovum with the same probability as a recessive but beneficial one, even if the two harmful genes together may doom the recipient. And mutations, as is well known, are more likely to produce genotypes that are less well adapted than those that carry already selected genes. Thus the process lacks the teleological direction seen in Lamarckian theories of evolution where the variations are willfully directed toward enhanced adaptation (Dawkins, 1986).

Campbell (1960) argued that the same striking nonteleological characteristic applies to the creative process. It is for this reason that he called his model one of "blind variation and selective retention." Campbell realized that the term *blind* may cause problems, and he and others after him have considered various alternatives, such as *chance, random, aleatory, fortuitous, haphazard, unrestricted, unjustified,* and even Darwin's own term *spontaneous* (Campbell, 1974b; Simonton, 1988e). But Campbell thought that *blind* had certain assets over the others. In the 1960 article he chose that descriptor because it denotes the lack of foresight in the production of variations—the inability to generate purposively the most adaptive variations (Simonton, 1995). The term also has the advantage of not committing the theory to any particular variation mechanism. For example, when a radar systematically sweeps the skies, it is acting according to the principle of blindness because it is not being guided by any a pri-

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[1] Actually, in the development of coevolutionary models of biological and cultural change, the distinction between primary and secondary Darwinism breaks down (e.g., Lumsden & Wilson, 1981). Similarly, evolutionary epistemology is actually of two kinds, one primary and the other secondary (Bradie, 1995).

[2] The original impetus for this article was my learning that Donald Campbell had died on May 5, 1996. I have also chosen to honor Campbell's contribution to creativity theory by a special issue of the *Journal of Creative Behavior* (Simonton, 1998a), which contains a contemporary evaluation of Campbell's 1960 article by Sternberg (1998), Perkins (1998), and Cziko (1998). A more extensive treatment of the relevant theory and data may be found in Simonton (1999a).

ori ideas about where an airplane or missile is most likely to be found.

To be sure, with respect to cognitive mechanisms, blind variations may be more prone to result from some variety of chance or random process. Yet it is important to recognize that even in this more restricted application blindness does not require that the variations be totally random in the sense of precise equiprobability for all possible alternatives. It is merely argued that the probability distribution of potential variations need not closely correspond to the probability distribution describing the variations that will actually prove successful. This is analogous to what occurs in biological evolution: Due to the constraints on crossover resulting from chromosomal linkage, certain genetic recombinations will be more probable than others. Yet the differential likelihoods of certain genotypes are not necessarily preordained to ensure greater reproductive fitness in the offspring.

Campbell (1960) did not rule out the possibility that some variations might be excluded on a priori grounds. He only suggested that the application of such criteria depends on the previous acquisition of knowledge through a blind-variation and selective-retention process (see also the “epistemic preadaptations” of Stein & Lipton, 1989). That a priori knowledge may have been the upshot of three separate Darwinian routes: (a) biological evolution by natural selection, which provides the neurological basis for human information processing (Plotkin, 1993); (b) individual trial-and-error learning, whether behavioral or cognitive (Skinner, 1938; Stein & Lipton, 1989); and (c) social learning (modeling and instruction) from other individuals who themselves acquired the knowledge through trial-and-error learning (cf. the “guided variation” of Boyd & Richerson, 1985). This accumulated wisdom could of course result in a situation where only one particular variation has a nonzero probability of being adaptive, but it is precisely such a circumstance in which creativity is not required. In the same way, a species can become so well adapted to its environment that the production of variations through sexual reproduction proves counterproductive. With the emergence of parthenogenesis, the one surviving variant has a 100% probability of appearing in the next generation.

Once Campbell (1960) specified the nature of his Darwinian model, his next task was to provide some documentation on behalf of his theory. He began by showing how other thinkers before him had promulgated the notion that creativity entailed a variation-selection procedure. For example, he quoted extensively from Alexander Bain (1855/1977), Ernst Mach (1896), and Henri Poincaré (1921). The latter quotations involved now-famous introspective reports that acquire tremendous weight given Poincaré’s status as a great mathematical innovator. Campbell also endeavored to link the theory with what was then known about the characteristics and circumstances underlying creativity, although from today’s perspective this effort now appears totally inadequate. The inadequacy stems not from the lack of sound scholarship on Campbell’s part but rather from the tremendous amount of research on creativity that has accumulated since 1960. This research makes the case on behalf of the Darwinian model more convincing than ever before (Eysenck, 1995; Kantorovich, 1993; Simonton, 1988e, 1993, 1999a).

Supportive Documentation

Much of the best support for Darwinian creativity comes from a somewhat questionable source, namely, the introspective reports of eminent creators. As already noted, Campbell (1960) quoted at some length from Poincaré’s (1921) record of what went on in his mind when he made his great mathematical discoveries. Many other creative individuals have offered corroborative introspections as well (e.g., Helmholtz, 1898; James, 1880). Particularly provocative are the diverse reports of serendipity (Austin, 1978; Cannon, 1940), because serendipitous discoveries have a role in cultural evolution similar to that of the mutation in biological evolution (Kantorovich & Ne’eman, 1989). Both are unexpected events that can set the course of historical change in new directions. Nonetheless, space does not permit an extensive citation of cases, something that has already been done anyway in the context of the Darwinian model of creativity (e.g., Eysenck, 1995; Kantorovich, 1993; Simonton, 1988e, 1999a). More important, the quality of these impressionistic data cannot really live up to scientific standards (Perkins, 1981). Many such reports occurred well after the fact, and even if the reports were proximate to the events described, there is considerable doubt about the adequacy of introspective information (e.g., Nisbett & Wilson, 1977). Accordingly, it seems a better strategy to skip these accounts and proceed directly to empirical studies that satisfy higher standards of scientific evidence. This supportive documentation comes from three rather distinct methodological domains: the experimental, the psychometric, and the historiometric. Because it is the blind-variation component of Campbell’s (1960) model that presents the most difficulty for most psychologists (e.g., Sternberg, 1998), the review of the evidence will concentrate on that portion of the Darwinian process (see also Cziko, 1998).

Experimental Evidence

Behavioral scientists have for a long time been interested in problem solving and creativity, most of the earliest work being associated with the Gestalt school of psychology (Dominowski, 1995). With the advent of modern cognitive science, the topic assumed new importance, and the amount of excellent research has substantially increased. This experimental work falls into two categories: laboratory studies of human creativity and computer simulations of human creative behavior.

Human creativity. Probably the oldest relevant research tradition is that concerning the insightful solution of problems (Sternberg & Davidson, 1995). Much of this experimental work has taken interest in what occurs during the incubation period that separates the individual's first attempt to solve a problem and the final arrival at a solution.[3] Many recent studies suggest that during this interval the individual is being exposed to all sorts of extraneous input, some external (everyday events as well as efforts on other projects) and others internal (retrieved memories, chains of associative thought), which are constantly "priming" different aspects of the mnemonic and semantic networks surrounding a given problem (see, e.g., Smith, 1995). Because the successful solution typically requires a complete reformulation of the nature of the problem, this largely random influx of priming stimuli produces a series of alternative formulations, some more fruitful than others but with only one eventually leading the individual down the correct path to solution (see, e.g., Seifert, Meyer, Davidson, Patalano, & Yaniv, 1995). In other words, during incubation the mind is engaged in an inadvertent blind-variation process, because the order in which the new conceptions appear will be determined by factors that are pretty much irrelevant to the problem (see also Mandler, 1995; Martindale, 1995). Indeed, it is the very extraneous nature of this input that is so essential to the solution to the problem. Participants get stumped on insight problems because the most obvious ways of thinking about them are going to prove abortive (Smith, 1995).

One asset of this interpretation is its applicability to reports from creative individuals about the origins of their insights. In the first place, creative individuals frequently report having their great insights in moments when they are engaged in activities having absolutely nothing to do with the problem at hand (Boden, 1991). The classic example, of course, is the Eureka experience of Archimedes in the bathtub. Yet it is just such circumstances that are most likely to permit the influx of that random stimulus that primes the correct avenue to the solution (Martindale, 1995). In the Archimedes case, the random input was his noticing that the water overflowed when he stepped into the tub. Second, it is characteristic of highly creative individuals that they tend to work simultaneously on a large number of loosely interconnected problems (Hargens, 1978; Root-Bernstein, Bernstein, & Garnier, 1993; R. J. Simon, 1974; Simonton, 1992a). Gruber (1989) referred to this rich activity as a "network of enterprises," a phenomenon amply seen in the scientific career of Charles Darwin himself (Gruber, 1974). Typically, the creator will switch topics when an obstacle seems to stymie a particular project. Hence, while the creator is incubating on one problem, he or she will be constantly but haphazardly bombarded with priming input from other projects, a subset of which may stimulate the appearance of a solution to the problem that had been "put on the back burner." Sometimes the novel impetus will come not from work, but rather from play, for creative individuals tend to have wide interests and to entertain themselves with hobbies that often bear some remote connection with their professional activities (Dennis & Girden, 1954; Root-Bernstein, Bernstein, & Garnier, 1995; R. J. Simon, 1974).

The main drawback to the experimental research on insight is the nature of the problems themselves. The typical insight problem has a well-defined answer. In fact, the connection between the problem and the solution is quite logical once the "trick" is known. Real creativity does not begin with the knowledge that there even exists a true answer, and thus the phenomenon is far more open ended. Recent attempts to develop the "creative cognition approach" have increasingly recognized this contrast, leading many investigators to ask participants to generate truly original ideas (Smith, Ward, & Finke, 1995). An excellent example is the experimental work associated with the Geneplore model of Finke, Ward, and Smith (1992). Although not explicitly formulated in Darwinian terms, the connection with a variation-selection framework is quite apparent. The very term *Geneplore* stands for "generate and explore," for the authors see the creative process as consisting of the generation of combinations followed by the exploration of their possibilities. In the experimental development of this model, the connection with a variation-selection process becomes even more obvious. Participants are given shapes or forms from which to construct objects with recognizable functions. The products of this combinatory play would then be evaluated by judges. Some of the inventions arrived at were truly ingenious, including a hip exerciser, a shoestring unlacer, and a hamburger maker. More interesting still was how the imaginativeness of the inventions would depend on the experimental conditions. Participants seemed to come up with the most practical and creative

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[3] Epstein (1990) attempted to explain insight in totally Skinnerian (variation-selection) terms, obtaining behaviors in pigeons that closely approximate those seen in Köhler's (1925) experiments concerning insight in chimpanzees. Discussion of this interesting work would take us too far afield, however (see Simonton, 1999a, for how this behavioristic theory is compatible with both psychoanalytic and cognitive theories of the creative process).

solutions when both the object parts that they had to work with and the category of object they had to invent were randomly selected from the larger pool of possibilities. The best creativity tends to be serendipitous rather than deliberate. One could hardly obtain a more “blind” basis for launching the combinatory process.[4]

If creativity requires the capacity to generate blind variations, then it is conceivable that the level of creative performance may be increased by any technique that might serve to break the stranglehold of conventional expectations. Some experiments have shown that this type of stimulation is indeed possible. A good example is experiments showing how exposure to the ambiguous juxtapositions of incongruous images stimulated artists to produce drawings that scored higher on creativity (Rothenberg, 1986; Sobel & Rothenberg, 1980). Likewise, randomly generated remote associations have been shown to enhance creative problem solving on a marketing task (Proctor, 1993). There have also been experiments showing that creativity tends to be more compatible with intrinsic rather than extrinsic motivation (Amabile, 1996), presumably because intrinsic motives are more conducive to the playful exploration of the materials in a domain (see also Getzels & Csikszentmihalyi, 1976; Staw, 1990).

Computer creativity. The bulk of the attempts to simulate creativity on a machine have tended to assume that the creative process was far from Darwinian (see Boden, 1991). Instead, the computer programs consist of step-by-step instructions that would lead to the solution with the absolute force of logic, or at least with the judicious use of a well-defined set of heuristic principles (e.g., Langley, Simon, Bradshaw, & Zythow, 1987; Shrager & Langley, 1990). This highly analytical and deterministic view of creativity largely reflected the underlying hardware and software (viz., the digital computers programmed with Boolean if–then statements). However, with the advent of other forms of computer architecture and programming, and especially with the emergence of parallel processing and connectionism, there exists more than one computer metaphor for the mind. Several researchers have suggested that these newer systems have the capacity to provide more realistic and explicitly Darwinian models of the creative process (e.g., Martindale, 1995). Such models have yet to constructed but hold tremendous promise in the future.

Nevertheless, an entirely different strategy has arisen directly from the Darwinian framework: genetic algorithms and genetic programming (Bäck, 1996; Goldberg, 1989; Koza, 1992). In this approach, combinatorial variations are created according to a process quite similar to Mendelian genetics, and mutations can be randomly added as well. The results are tested against a selection criterion, the most successful combinations then making genetic contributions to the next generation. The whole cycle repeats until a “genotype” emerges that fits maximally the “environmental” criterion. Not only has this Darwinian procedure been applied to the solution of genuine practical problems, but sophisticated computer programs have been written as well. Of special interest are demonstrations that certain key discoveries in science, such as Kepler’s Third Law of Planetary Motion, can be rediscovered by this totally Darwinian means (Koza, 1992). Although these methods are still in their infancy, they already provide ample testimony to the potential explanatory power of selectionist models of creativity in which the variation mechanism is completely blind by design (see also Adleman, 1994).

Admittedly, not all computer programs that seem to simulate human creativity successfully do so by mechanisms so blatantly Darwinian (Johnson-Laird, 1993). Many programs impose more a priori constraints on what conceptual variants will be produced. Nonetheless, if Campbell (1960) is correct, all programs that generate truly human-like forms of creativity should include some mechanism for the unguided, even random exploration of the conceptual space that remains after such a priori restriction. As Boden (1991) put it in her extensive review of such simulations, “what is useful for creativity in minds and evolution is useful for creative computers too. A convincing computer model of creativity would need some capacity for making random associations and/or transformations” (p. 226), and she noted that many successful creativity programs actually accomplish this “by reference to lists of random numbers.” Indeed, to simulate genius-level creativity, not only must this blind-variation process become more prominent, but in addition there should be some provision for subjecting the constraints themselves to ideational variation (Boden, 1991). The most notable creators, such as Newton, Michelangelo, and Beethoven, were those who explored new idea-generating rules rather than confining themselves to old standards.

Psychometric Evidence

No theory of creativity can ignore one fundamental fact: Individual differences in creative behavior are huge (Simonton, 1988e). In the first place, only a relatively small percentage of the population seems capable of publishing even a single poem in a major literary magazine, exhibiting even a single work of art in an important museum, or obtaining the patent for a commercially successful invention. For example, one

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[4] It is interesting that individuals who can freely access their right hemisphere—an ability often associated with creativity—find it much easier to generate random numbers (Charlton & Bakan, 1990).

study looked at those who had received doctoral degrees at a major research university (Bloom, 1963). Although these new doctorates already represented an extremely select group of intellects, fewer than half went on to publish anything beyond their doctoral theses (see also Getzels & Csikszentmihalyi, 1976). Moreover, even when we confine attention to just those individuals who make at least one contribution to a field of creative activity, the cross-sectional variation in output remains substantial (Simonton, 1984b). Usually about 50% of all creative ideas come from those in the top 10% of the productivity distribution, whereas those in the bottom half of the distribution are responsible for only about 15% of the total output (Dennis, 1954a, 1954b, 1955). In fact, according to the Price Law, the number of individuals responsible for half of all contributions is approximately equal to the square root of the total number of individuals making at least one contribution (Price, 1963). This disparity can happen because the productivity distribution is extremely skewed, with a tremendously long upper tail (Lotka, 1926; Price, 1963; Shockley, 1957; H. A. Simon, 1955).

How can the behavioral scientist predict this substantial cross-sectional variation? Are there any cognitive or personality traits that differentiate the most prolific contributors from those who produced just one contribution, or even none? Psychometricians have attempted to address this question via two separate routes: creativity tests and personality assessments.

Creativity tests. Although the original IQ tests were conceived as measures of human intelligence, and hence problem-solving ability, it soon became clear that a high IQ did not guarantee a capacity for genuine creativity (Barron & Harrington, 1981; Haensly & Reynolds, 1989; Sternberg, 1985). To be sure, it is most unlikely that individuals with low IQs would have the ability to exhibit notable creativity. Even so, above a certain minimum IQ, further increases in intelligence scores need not be associated with enhanced creative performance (see Simonton, 1985a). This fact led a number of investigators to devise tests of creativity that assessed those intellectual capacities not captured by standard intelligence tests. One early example is the Remote Associates Test (RAT) of Mednick (1962). This test was based on the premise that creativity involves the ability to make rather remote associations among separate ideas. Highly creative individuals were said to have a flat hierarchy of associations in comparison to the steep hierarchy of associations of those with low creativity. A flat associative hierarchy means that for any given stimulus, the creative person has a great many associations available, all with roughly equal probabilities of retrieval. Because such an individual can generate many associative variations, the odds are increased that he or she will find that one association that will make the necessary remote connection. The RAT can therefore be said to operate according to an implicitly variation-selection model of the creative process.

The Darwinian basis is even more apparent in other tests that purport to measure creativity. Guilford (1967), one of the pioneers in the psychometric study of creativity, proposed a profound distinction between two kinds of thinking. Convergent thought involves the convergence on a single correct response, such as is characteristic of most aptitude tests, like those that assess IQ. Divergent thought, in contrast, entails the capacity to generate many alternative responses, including alternatives of considerable variety and originality. Guilford and others have devised a large number of tests that purport to measure the capacity for divergent thinking (e.g., Torrance, 1988; Wallach & Kogan, 1965). Typical is the Alternate Uses test in which the individual must come up with many different ways of using a common object, such as a paper clip or brick. Many investigators have tried to validate these divergent-thinking tests against other criteria of creative performance (see, e.g., Crammond, 1994). Although these validation studies have had some modicum of success, it has also become clear that generalized tests do not always have as much predictive validity as tests more specifically tailored to a particular domain of creativity (Baer, 1993, 1994; for discussion, see Baer, 1998, and Plucker, 1998). Creativity in music, for example, is not going to be very predictable on the basis of how many uses one can imagine for a toothpick.

Even so, from a Darwinian perspective we would not expect it to be otherwise. The variation-selection process must operate on those concepts that belong to a specific discipline. Hence, tests of divergent thinking must be tailored to each domain. This constraint is somewhat analogous to what is seen in biological evolution: Short of a highly fortuitous coincidence in protein synthesis, abundant spontaneous variation in wing pigmentation will probably not aid a herbivorous insect species that needs to generate variations in digestive enzymes to counteract a new chemical defense adopted by its main food source.

One final complication must be acknowledged as well: Different forms of creativity will require varying amounts of remote association and divergent thought (Hudson, 1966). On the one hand, because artistic creativity tends to put more stress on originality, the variation process must be much more free (and might even include alternative uses for a toothpick, as in surrealistic art). On the other hand, scientific creativity places more emphasis on satisfying certain theoretical and methodological standards, and thus the variation process operates under more a priori constraints. Moreover, within each of these two major forms of creative activity, contrasts will appear in the relative “blindness” of the variations. For example, individuals who launch scientific revolutions will exhibit more far-ranging imaginations than those who practice what Kuhn (1970) called “normal science.” Likewise, avant-garde artists will prove more radical than the artists of the academies. Indeed, academic artists may function under the same magnitude of constraint as a scientific revolutionary, and hence the two distributions will overlap. In any event, just as some species exhibit higher mutation rates (or permit greater genetic crossover, or both), so will some creativity disciplines display more intense variational activity than others. These interdisciplinary contrasts will reappear elsewhere in this article.

Personality assessments. A huge body of research has accumulated that addresses the distinctive personality profile of creative individuals (Barron & Harrington, 1981; Feist, 1998; Martindale, 1989; Sternberg & Lubart, 1995). The picture of the creative person is quite compatible with what we would expect to be necessary from a Darwinian view of creativity (Eysenck, 1993, 1995; Simonton, 1988e, 1989b). That is, creative personalities tend to possess those characteristics that would most favor the production of ideas both numerous and diverse. In particular, creative individuals tend to be independent, nonconformist, unconventional, even bohemian; they also tend to have wide interests, greater openness to new experiences, and a more conspicuous behavioral and cognitive flexibility and boldness (see Simonton, 1999a).

Among the more provocative findings is the tendency for highly creative individuals to exhibit a certain amount of psychopathology (Barron, 1963; Eysenck, 1995; see also Andreasen, 1987; Jamison, 1989; Ludwig, 1995). So long as incapacitating mental breakdowns are avoided, psychopathological symptoms can facilitate Darwinian creativity by increasing the number and scope of variations generated (see, e.g., Slater & Meyer, 1959; Weisberg, 1994). An excellent example is the connection between creativity and moderately high scores on the psychoticism scale of the Eysenck Personality Questionnaire (Eysenck, 1993, 1995). Individuals scoring at moderate levels on psychoticism tend to display such useful traits as nonconformity and independence, whereas at the same time exhibiting the capacity for original thought processes (see also Eysenck, 1994; Rushton, 1990). Those showing some amount of psychoticism even process information in somewhat unusual ways, including certain cognitive quirks (e.g., regarding “latent inhibition” and “negative priming”; Eysenck, 1995). As a consequence, creative individuals are a little bit off-beat, contemplating the world around them in a manner a bit odd, in part because they fail to filter the extraneous influence of haphazard stimuli from their internal and external worlds. Concomitantly, they do not feel the inhibiting necessity of forcing their crazy hunches to conform to social and disciplinary conventions. This is an ideal situation for the production of ideational mutations.

Of course, because the degree of free variation varies across distinct domains of creativity, the expected personality profiles should follow suit. For example, artistic creators should exhibit higher levels of psychopathology than do scientific creators, and that is in fact the case (Cattell & Butcher, 1968; MacKinnon, 1978; Roe, 1952). The other character traits that distinguish creators from noncreators also tend to distinguish creative artists from creative scientists (Simonton, 1988e). In general, scientific creativity tends to fall between artistic creativity and noncreativity, at least for those attributes directly linked to the capacity for unrestricted ideational variation. This pattern continues down to lower levels of resolution as well. An excellent example is the distribution of psychopathology across various types of artistic creativity: Artists whose work emphasizes logic, objectivity, and formalism display lower rates of mental illness than those whose work stresses intuition, subjectivity, and emotionalism (Ludwig, 1998).

Historiometric Evidence

Creativity at the highest level will have such an extensive impact on human culture that individuals will leave a lasting imprint on the annals of history. Darwin himself amply illustrated this phenomenon. Historical data about the lives, careers, and circumstances of eminent creators can then be subjected to statistical analyses to determine the factors that underlie the emergence of creative genius (Simonton, 1990). The factors revealed in historiometric research tend to fall in line with what we would expect from a Darwinian model. For instance, the historiometric literature reinforces the conclusions of the psychometric literature, including the personality profiles of creative individuals (Cattell, 1963; Ludwig, 1995). In addition, historiometric studies have revealed corroborating findings in the areas of talent development, professional careers, stylistic change, and the sociocultural environment.

Talent development. Any developmental factor that enhances the capacity of an individual to generate numerous and diverse variations should have a positive impact on the development of creative potential. One of the most obvious requirements is the early acquisition of the required expertise to make contributions to a domain, a requirement that usually takes about a decade of intense study and practice (Hayes, 1989; Simonton, 1991b; see also Ericsson, Krampe, & Tesch-Römer, 1993). However, it is essential to realize that expertise alone does not guarantee creativity (Simonton, 1996a). The expertise must be organized in a way that it favors the production of multiple perspectives, and that expertise must be possessed by an individual willing to develop those divergent variations (see, e.g., MacKinnon, 1978; Rostan, 1994). Consequently, the development of creative talent should include events and circumstances that encourage nonconformity, independence, appreciation of diverse perspectives, a variety of interests, and other favorable qualities.

That indeed appears to be the case. For instance, eminent creators are more likely to have come from unconventional family backgrounds (Simonton, 1994). Thus they may arise disproportionately from among immigrants (Goertzel, Goertzel, & Goertzel, 1978; Helson & Crutchfield, 1970), and they may have come from homes that suffered the loss of one or both parents (Eisenstadt, 1978; Roe, 1952; Walberg, Rasher, & Parkerson, 1980). Although creative talent is nourished by the presence of models and mentors in the future domain of achievement (Walberg et al., 1980), creative potential is best nurtured by having many diverse sources of influence rather than just one (Simonton, 1977b, 1984a, 1992a). Moreover, even though formal education may be necessary to provide the minimal expertise for achievement as a creative individual, such training can go too far as well, restricting the diversity of perspectives required for true creative success (Simonton, 1976a, 1983, 1984b). Indeed, many of the most innovative ideas in a domain often have received their initial training in other fields (Gieryn & Hirsh, 1983; Hudson & Jacot, 1986; Kuhn, 1970; Simonton, 1984c). This professional marginality allows the innovators to proliferate variations that would be excluded a priori by those who received their training totally within the discipline (see Simonton, 1999a, for more detailed discussion).

It is noteworthy that the distinction between artistic and scientific creativity is also relevant here. Developmental events that tend to nurture originality are prone to be much more frequent or intense in the lives of artistic creators relative to scientific creators (Berry, 1981; Goertzel et al., 1978; Raskin, 1936; Simonton, 1984b, 1986a; see also Schaefer & Anastasi, 1968). For instance, rates of parental loss are higher among artists; artists also tend to come from more diverse backgrounds and they tend to obtain less formal education.

Professional careers. Once a creative individual has developed the necessary creative potential, he or she is in a position to actualize that potential in the form of a career of creative output. These careers have several features that are most compatible with a Darwinian view of creativity. Probably the most remarkable feature is the consistent relation between quantity and quality (Simonton, 1984b). In biological evolution, those individuals who produce the most total offspring will usually have more offspring survive to reproduce themselves. But the more prolific organisms will also tend to produce the most progeny who die before reaching maturity. Thus reproductive success is often associated with reproductive failure. A similar pattern is observed in the careers of eminent creators (Cole & Cole, 1973; Davis, 1987; Dennis, 1954a, 1954b; Feist, 1993). Those who are the most prolific will have the most successful works, but they will also have the most unsuccessful works. So, quality is strongly associated with pure quantity. Produce more variations, and the odds will be increased that some variations will survive.

This quality–quantity association applies to other features of careers as well, such as the differences seen between men and women (Over, 1990). Men may produce more influential works than women, but they also produce more ignored works in equal proportion, so that the hit rate per work offered is not contingent on gender. Even more remarkably, this same relation holds within careers, not just across careers. The mathematical function that describes the changes in creative output across the life span is the same for successful and unsuccessful products (Simonton, 1988a, 1997a). Those periods in which the creator produces the most total works will be those in which the most outstanding works appear, including the single best contribution (Simonton, 1991a, 1991b). In fact, the ratio of successful products to total output fluctuates randomly throughout the career (Simonton, 1977a, 1984b, 1985b). In other words, the expected probability of success stays constant regardless of the creator's age, yielding what has been called the "equal-odds rule" (Simonton, 1997a; cf. Simonton, 1988a). Because of this principle, creative individuals are not able to increase their hit rates, nor do the hit rates decline with age, nor even will they exhibit some curvilinear form (Over, 1988, 1989; Simonton, 1977a, 1984b, 1985b, 1997a; Weisberg, 1994). The fascinating aspect of this principle is that it is what we would predict from the Darwinian viewpoint. If the variation process is truly blind, then good and bad ideas should appear more or less randomly across careers, just as happens for genetic mutations and recombinations (with the minor exception of certain chromosomal abnormalities).

Other aspects of the creative career can also be subsumed under a Darwinian model, although we do not have the space to discuss the details here (see Simonton, 1988e, 1997a, 1999a). Thus variation-selection theory has been used to explain and predict (a) the skewed probability distribution of lifetime output (Simonton, 1988e, 1997a; cf. Simonton, 1999b), (b) the role of social networks in the maintenance of creativity across the life span (Allison & Long, 1990; Simonton, 1992a, 1992b), (c) the long-term stability of a creator's reputation (Over, 1982; Simonton, 1988e, 1991c, 1998b), and (d) the distinctive career trajectories, including the longitudinal location of career landmarks and the differences across the various domains of creative achievement (Simonton, 1991a, 1991b, 1997a).

Stylistic changes. Martindale (1990, 1994) developed a Darwinian model that explains the changes seen in aesthetic styles as a particular tradition evolves over time. Creative ideas result from a free-associative, combinatory process that generates the aesthetic variations. However, each generation of aesthetic creators—whether poets, composers, or artists—is under unrelenting pressure to produce works that have more "arousal potential" (i.e., shock value) than the works of their predecessors. This inspires the variation process to resort to ever more "primordial cognition," or what is called *primary process* in the psychoanalytic school of psychology (cf. Suler, 1980). As the variations become increasingly extreme, the style begins to break down. Eventually the aesthetic tradition undergoes a kind of revolution in which a new style replaces the old. The works produced in the new style do not rely so much on primordial cognition to obtain the needed novelty, but subsequent creators will have to dig up increasingly original combinations, and the whole process repeats. The consequence is a series of stylistic cycles.

One intriguing feature of Martindale's (1990) theory is that it has closer affinities with sexual selection than with natural selection. The trend toward ever more original creative products is similar to how sexual selection may push a particular trait or behavior toward some extreme, such as the tails of peacocks or the plumage of male Birds of Paradise. As in sexual selection, too, the end result may be maladaptive from the standpoint of the environment. When a stylistic tradition reaches the evolutionary cul-de-sac, the outcome is the output of poems, compositions, or paintings that may be autistically obscure and indecipherable.

More important, however, is the fact that Martindale has applied computerized content analysis to actual poetry in the French and English traditions to document how the theory can indeed account for stylistic change (Martindale, 1975). He has also tested his theory using creative products in fiction, music, and the visual arts (Martindale, 1990). He has even made initial efforts toward extending the model to creativity in the sciences and humanities. So far the results fit what Martindale predicted from his Darwinian model of creativity.

Sociocultural environment. It has long been known that creative personalities are not randomly distributed across either cultures or historical periods, but rather such individuals will cluster into what have been termed *cultural configurations* (Kroeber, 1944; Simonton, 1988c, 1996b). Certain times and places will exhibit a "Golden Age" resplendent with numerous creative minds of the highest order, whereas elsewhere a society may be dominated by a "Dark Age" where not a single creative idea sees the light of day. This fact suggests that there are special political, cultural, economic, and societal circumstances that may serve either to encourage or repress the development and manifestation of the individual capacity to generate variations. Although the number of such factors is very large (Simonton, 1984b), the more important of these influences would seem to operate in a manner consistent with what we would predict from a Darwinian theory (Simonton, 1988e). For one thing, the zeitgeist seems to encourage individuals to generate new variations, including new combinations of ideas. In particular, we may note the following:

1. Creative individuals are most likely to appear when a multiethnic civilization is fragmented into a large number of separate nations, which would presumably enhance the cultural heterogeneity while permitting cross-fertilization of ideas (Naroll et al., 1971; Simonton, 1975, 1976d; Sorokin, 1947/1969). The city-states of the Greek Golden Age and the Italian Renaissance offer typical instances. Moreover, when a civilization area is dominated by a single imperial state, such as was Europe under the Roman Empire, then nationalistic rebellions will tend to resuscitate the level of creativity (Simonton, 1975).
2. When a civilization is characterized by conspicuous ideological diversity—the presence of numerous rival philosophical schools—then creativity tends to increase, even in those domains that have relatively little to do with intellectual trends (Simonton, 1976c).
3. After a civilization opens itself up to foreign influences, it tends to become the site for a revival of creative activity (Simonton, 1997b). This alien input may take several forms, including study abroad, mentorship under a foreign master, or the immigration of individuals from the outside. The latter fits in with what we noted earlier about immigrants. Moreover, these findings are compatible with laboratory experiments showing how the presence of minorities can enhance divergent thought processes (Nemeth, 1986; Nemeth & Kwan, 1985, 1987; Nemeth & Wachtler, 1983). The process operating here is not unlike the possible role of hybridization in the generation of new biological species (Harrison, 1993).[5]

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[5] Also congruent with this line of thinking is the research indicating that second-language learning and bilingualism is often associated with increased creativity (Carringer, 1974; Lambert, Tucker, & d'Anglejan, 1973).

On the other hand, other external conditions may inhibit the production of the ideational variations that feed the creative process. For instance, because original thought is prevented when an individual is in a state of high emotional arousal (Martindale, 1995), it should come as no surprise that threatening circumstances, such as war, tend to lower the level of creativity observed in a given society (Simonton, 1980b, 1984b). In fact, such conditions tend to support the opposite of societal creativity, namely, authoritarianism, dogmatism, and rigidity (Doty, Peterson, & Winter, 1991; Sales, 1973; Simonton, 1976e).

Finally, we should point out, once more, that artistic and scientific creativity require somewhat different circumstances (Simonton, 1976b). Although both require a zeitgeist that supports the free exploration of ideas, scientific creators appear to require more stable sociocultural settings than do artistic creators (Simonton, 1975). As an example, political anarchy has a much more debilitating effect on the sciences and allied activities than it does on the arts (Simonton, 1975, 1976d).

Potential Objections

Not every researcher who has studied creativity can be considered sympathetic with the notion that the creative process is fundamentally Darwinian (see, e.g., Perkins, 1994; Weber, 1992). Of the many possible objections, I would like to address four here: sociocultural determinism, individual volition, human rationality, and domain expertise.

Sociocultural Determinism

The first objection concerns whether Darwinian models are compatible with the apparent sociocultural determinism that supposedly governs scientific discovery and technological invention. Several sociologists and anthropologists have argued that the contributions to science and technology are not individualistic but rather are the consequence of the inexorable operation of the zeitgeist (Kroeber, 1944; White, 1949). The convincing proof of this position is said to be the phenomenon of multiple discovery and invention, that is, where two or more individuals working independently of each other arrive at the same contribution, and often simultaneously (Lamb & Easton, 1984). Among the classic instances is the idea of evolution of natural selection itself, which was conceived separately by Darwin and Wallace and then offered simultaneously to the scientific world. Supposedly these multiples demonstrate not only that the individual creator is irrelevant but additionally that the process of creation is totally deterministic (Merton, 1961). At a certain point in history, particular ideas become absolutely inevitable; the ideas are "in the air" for anyone to discover (Ogburn & Thomas, 1922).

Although this social deterministic view seems to run counter to the Darwinian perspective, detailed quantitative analyses of the data on multiples show that this phenomenon is actually most concordant with the notion that science is indeed Darwinian (Simonton, 1988b, 1988e). In particular, the distinctive probability distribution of multiple grades (i.e., the number of independent discoveries) as well as the probability distribution of the time lapse among the separate discoveries can be explicated in terms of stochastic models that are completely explicable in terms of a variation-selection theory (Brannigan & Wanner, 1983; Price, 1963; Simonton, 1979, 1986c, 1987). In these models, diverse recombinations of ideas are randomly generated in multiple individuals, with the sole constraint that combinations that have already appeared will not be duplicated once their appearance has sufficiently disseminated (by incorporating a "contagion mechanism" in the stochastic process). These models can still reproduce the observed probability distributions when an a priori ordering is imposed on the permissible combinations and thereby allow that some ideas may be necessary (but not necessary and sufficient) for the appearance of other ideas. The Darwinian models also successfully predict that the odds of any one individual participating in a multiple is a probabilistic function of the person's own productivity and the aggregate output of colleagues working in the same field (and hence submitting the same ideas to combinatorial variations; see Simonton, 1999a).

In truth, the occurrence of multiples threatens a Darwinian theory of creativity no more than the multiple invention of wings in the biological world (by insects, fish, birds, and mammals) undermines a variation-selection explanation for the origin of species (see also Simonton, 1976c, 1980c, 1999a).[6] Convergent evolution retains a Darwinian etiology.

Individual Volition

The second objection concerns what is often considered a fundamental difference between biological and sociocultural evolution: the role of personal will. In the modern version of the evolutionary theory—unlike in so-called Lamarkianism—the changes that take

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[6] The comparison suggested here is much closer than might be gathered from first inspection. Not only are many so-called "multiples" actually far from constituting identical creative products, but their intellectual origins are often quite distinct, and thereby they represent bona fide instances of the parallel evolution of analogous adaptations (Simonton, 1988e; see also Constant, 1978; Patinkin, 1983; Schmookler, 1966).

place in population gene pools are undirected. There is no agent overtly trying to enhance the reproductive fitness of either individuals or species. To be sure, there exists an active debate about the possibility of "directed mutation," but this issue is far from being resolved and still only involves the hypothesis that mutations in certain simple organisms might exhibit foresight (Lenski & Mittler, 1993).[7]

Yet it is very clear that sociocultural evolution does indeed have agents—the creators themselves. Creative individuals have goals, aims, aspirations, plans; they are struggling to overcome obstacles in the path of self-expression or world discovery (see, e.g., Gruber, 1989). Even so, the goal-directedness of creativity can be admitted without denying whatsoever that the underlying process is Darwinian (Cziko, 1995; Simonton, 1988d). The individual creator, even the greatest creative genius, cannot simply will discoveries and masterpieces to happen. If otherwise, it is hard to comprehend why a failure can follow on the heels of a big success. Whenever the problem at hand requires genuine creativity, there will be a point where the individual has no other option but to relinquish control to a blind-variation process, such as playful exploration, haphazard tinkering, and free association. Indeed, the phenomenon of serendipity shows how the solution to a problem will often appear where least expected. In these circumstances, the only option left for the will is to keep the creator on track, to maintain the dogged persistence necessary to keep the brain working on a problem, even if only in the back of the mind. Hence, the existence of will and willpower in creative lives does not make the creative process itself any less Darwinian. After all, in genetic programming we do not conclude that the process is non-Darwinian simply because someone wrote a program with the purpose in mind that a particular problem be solved.

Human Rationality

Just as Darwinian creativity seems to have dethroned both society and volition as important forces in creativity, so has it removed reason as a major factor as well. This runs counter to a major school of problem-solving research that sees all creativity as simply a straightforward application of conscious, logical, and deliberate analysis (Hayes, 1989; Newell & Simon, 1972; Perkins, 1981). In this tradition, all that is necessary is first to find the most appropriate representation of the problem and then to use the most suitable heuristics to work through the problem space (e.g., Kaplan & Simon, 1990). Even the most outstanding examples of creativity are not believed to involve more than this (see, e.g., Qin & Simon, 1990). Indeed, it is from this school that have emerged the most prominent attempts to write computer programs that purport to make scientific discoveries (e.g., Langley et al., 1987).

Although this view of problem solving seems diametrically opposed to the Darwinian perspective, on closer inspection they may not be incompatible at all. To appreciate this possibility, we must consider the extreme variation in the nature of problems.

To begin at the lowest level, some problems are very basic. The proverbial example is the query 2 + 2 = ?. Because the answer to this problem has probably been memorized, the response can be simply retrieved from memory. The problem 235 + 479 = ?, in contrast, must be answered not through memory retrieval but rather through the application of a simple algorithm for the addition of multiple-digit numbers. As we make the problems more complex, such as happens in many attempts to solve differential equations, straightforward algorithms are no longer available. In these cases, solution is contingent on finding the proper representation and heuristics that will lead to solution with only the minimal amount of trial and error. Yet as the problems become ever more novel and complex—as in, say, the three-body problem in physics—even this approach breaks down. The number of possible representations becomes very large, the number of potentially applicable heuristics quite immense. The individual has no other choice but to try out the alternative representations and heuristics. Moreover, as the problem becomes ever more unprecedented, the diverse alternative approaches to tackling the problem will become not only more numerous but increasingly equiprobable besides. This distinctive status makes the probability of considering any one strategy highly contingent on the priming effects of random stimuli from the outside world. This process of priming problem-solving variations will be inherently blind. That is, sometimes these extraneous inputs will set the mind off on the wrong direction, and other times they will inspire a more fruitful chain of associations or "spreading activation" (see Findlay & Lumsden, 1988). Therefore, when a person is dealing with a truly notable act of creative problem solving, the process must be essentially Darwinian. The creator must be blindly trying out alternative representations, problem spaces, and heuristic searches (cf. Richman, Gobet, Staszewski, & Simon, 1996). Even worse, the creator may be simultaneously groping and stumbling through the space of possible problems, hoping to find that diminutive subset that is amenable to solution (Loehle, 1990).

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[7] Actually, the variational process in organic evolution may show a certain amount of foresight in terms of the magnitude of variation that is permitted for various adaptations. Certain regions of a genome's DNA sequences may feature higher mutation rates than the rest because these are under strong and constant selection pressure for rapid evolutionary change (Pennisi, 1998). To some undetermined extent, too, chromosomal linkage may reflect selection toward maintaining the coherence of certain combinations of genes.

These last statements should not be misinterpreted as saying that the creative individual is engaged in a systematic, deliberate, and conscious process of testing various rival strategies. On the contrary, it is very likely that when a straightforward attack on the problem fails, the information processing may degenerate into a more haphazard, undirected, and unconscious mode of problem solving. The experimental research on the incubation period during the solution of insight problems provides us with some clues about how this regressive process may work. As already noted, during the incubation phase the individual is open to the uncontrolled influx of priming stimuli that constantly send the mind off into different trains of thought. Because we have ample experimental evidence that this priming process occurs at unconscious levels of processing (Bowers, Farvolden, & Mermigis, 1995; Bowers, Regehr, & Balthazard, 1990), the diverse ideational variations will also occur with little overt awareness (Simonton, 1980a; see also Hadamard, 1945). More than that, there is even experimental evidence that the insistence of conscious problem solving during this crucial stage of incubation may actually inhibit the individual from attaining the required insight (e.g., Schooler & Melcher, 1995). Consciousness, by relying excessively on the "tried and true," will necessarily restrict the range of the search, excluding those avenues of thought that are most likely to reach the solution. As the research suggests, conscious problem solving works most effectively for well-defined problems that do not depend on the intervention of a blind variation-selection process.[8]

Domain Expertise

The last objection comes from the accumulated research on the acquisition of expertise in a particular performance domain (Ericsson et al., 1993). Although this work has concentrated on well-defined skills, such as those found in sports, games, and music, the same principles would presumably apply to creative behavior as well (Ericsson, 1996). Once individuals acquire the requisite body of knowledge and master the domain-specific collection of perceptual and behavioral techniques, they should be able to generate a series of successful creative ideas without the trial and error implied by Campbell's Darwinian model. If the champion chess player can consistently win game after game, why can't the creative genius conceive one successful product after another?

What makes this challenge especially persuasive is its compatibility with two entirely different phenomena that would seem to lead to the same inference. The first is the operant conditioning phenomenon studied by Skinner and his school. Behavioral research has shown that performance on creativity measures can be treated as an operant and as such can be reinforced through standard procedures (Eisenberger & Cameron, 1996). If so, then why shouldn't creators also be able to increase their creative success in response to the reinforcements (and punishments!) they receive from readers, audiences, critics, colleagues, and the like?

The second phenomenon is even more intimately related to evolutionary theory, namely, the existence of alternative reproductive strategies (Pianka, 1970; Wilson, 1975). On the one hand, there are the so-called *r*-strategies in which individual organisms mass-produce progeny in the blind hope that a small percentage will survive to carry on their genes in the next generation. On the other hand, some animals, and especially birds and mammals, adopt the *K*-strategy of holding down the total output of offspring but substituting parental care to increase the odds that those offspring will survive and reproduce their kind. It would seem that the model here advanced entails only the *r*-strategy; creators are presumed to proliferate tons of ideas with the pessimistic expectation that only a few will get past the selection phase of the creative process. But why can't people use their accumulated expertise to switch over to a *K*-strategy? Maybe the youthful creator will grope in the dark, but the mature creator will be able to increase the odds of success.

One solution to this well-conceived objection is simply to point to the facts already cited: There is no evidence that the ratio of hits to total attempts increases with age. Creative failures are randomly dispersed with successes throughout the career. Darwin could follow his highly acclaimed theory of evolution by natural selection with his much-ridiculed theory of pangenesis, for example. But I think it more fruitful to pinpoint three more fundamental reasons why the equal-odds rule may be an essential aspect of the creative career.

First, the acquisition of expertise in a skill domain requires precise and consistent feedback on the quality of performance. This requirement is explicit in the operant conditioning paradigm, but it is also implicit in the work on expertise. It is no accident that the latter research has tended to focus on domains in music performance, games, and sports in which the criteria of success and failure are so well defined that expertise can be closely evaluated through both coaching and competition. Hence, it is relatively easy for an aspiring expert in these domains to learn precisely what is necessary to attain world-class mastery of the skill.

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[8] Nonetheless, there are many occasions in which creators will engage in conscious and deliberate blind variations (e.g., when inventors tinker around in the shop or artists exploit aleatory methods). An especially dramatic example is how James D. Watson (1968) discovered the DNA code by playing around with cardboard models of the bases.

This contrasts greatly with the situation of an ambitious creator. Because the criteria of success and failure are not so well defined, the feedback from the environment will often be highly inconsistent. Critics may disagree among themselves and with the general public; some colleagues may praise the new direction while others lament that the individual is "going off the deep end." It is rare for any major creative product to get a unified response from all the pertinent evaluators in the domain. Even worse, the criteria of success are not just inconsistent but unstable besides. A work might be a hit one year only to quickly sink into oblivion, whereas another work might be a "sleeper" that only catches on after considerable time delay (see, e.g., Simonton, 1998b). Moreover, this temporal instability in the judgmental standards may be intrinsic to the phenomenon. Styles and paradigms are always changing; new facts, concepts, and techniques are constantly emerging, so that the creator must cope with a constantly moving target (Kuhn, 1970; Martindale, 1990; Simonton, 1980c). The very same creative product that might have been a big success might be a total failure if it emerged only 1 year too late. Finally, unlike the circumstance in genuine skill domains, the environmental feedback is seldom highly differentiated. Usually all the creator gets is a global reaction from critics, colleagues, and the public at large. The piece enters the best-seller list or goes out of print; it receives performances throughout the world or bombs opening night; it receives citation after citation in the professional literature or passes away unread and ignored. Seldom does the creator receive a detailed (and both consistent and stable) critique from all interested parties about a creation's strengths and weaknesses. How fast would a violinist or gymnast acquire his or her expertise if the coaches restricted themselves to saying merely "good" and "bad" without providing specifics?

Second, the very nature of the creative product seems to militate against the acquisition of the necessary expertise. A poem, painting, symphony, journal article, novel, or other creation is a highly complex entity, with many dimensions that determine success or failure (see, e.g., Martindale et al., 1988; Shadish, 1989; Simonton, 1989a). Not only are these dimensions numerous, but in addition certain variables may function via nonlinear and nonadditive functions. For example, the aesthetic impact of a musical composition is a curvilinear, inverted-U function of its melodic originality (Simonton, 1980c; Vitz, 1964). Thus the composer is required to find just the right level of originality. This is no easy task, especially if Martindale's (1990) theory is correct, for then the optimal level of originality will be constantly changing over time as audiences become habituated to once avant-garde artistic forms. Furthermore, there is indirect evidence that the various contributing factors work through multiplicative rather than additive functions. To begin with, additive models, even when they contain numerous variables, seldom account for more than a few percent of the variance in the differential success of creative products (e.g., Shadish, 1989; Simonton, 1980c, 1986b, 1989a). Moreover, the frequency distribution of the differential success of creative products follows a highly skewed lognormal distribution, which is what would be predicted from a multiplicative rather than additive function (see, e.g., Simonton, 1986b). Hence, a creative product may not have an optimal impact unless it has just the right configuration of attributes, everything set at just the right level, and each attribute perfectly coordinated with all other characteristics. No wonder, then, that the environmental feedback is so inconsistent, unstable, and imprecise. There are simply too many relevant factors, participating in intricate curvilinear and multiplicative relations, for anyone, including the creator, to discern why one product hits whereas another misses.

Third, the human capacity for information processing may just not be up to the required task. There is a great deal of research showing that the human intellect is not very effective at even relatively simple inferences (Faust, 1984; Fiske & Taylor, 1991; Kahneman, Slovic, & Tversky, 1982). The mind can usually only handle a few independent dimensions at a time—hovering around G. A. Miller's (1956) "magic number" of 7 ± 2. Even worse, these dimensions usually can only be combined in simple linear and additive relations. If the functions become more complicated, then the number of dimensions must be correspondingly reduced. Therefore, it is very possible that neither the creator nor the evaluators of creative products have the capacity to discern the intricate configurational relations that are most conducive to success. The implicit theories that they come up will be too simple to be correct and so will have insufficient utility to guide the acquisition of a genuine expertise. Even if the creator were extremely prolific, and thus had many experiences of trial and error, his or her intellect would not support the sophisticated inferences necessary to construct a reliable expertise. So perhaps the creative individual has no other recourse than to submit to the process of blind variation and selectivere tention. The creator must toy around with the myriad dimensions that define a particular genre in the blind hope that every so often just the right configuration appears.

This is not to say that there do not exist certain domains where an individual can exhibit something akin to creative expertise. If the standards of creative success are sufficiently simple and well defined, and if disciplinary evaluations are consistent, stable, and precise, then certainly persons might become sufficiently expert to engage in a *K*-strategy. Perhaps certain scientific specialties that are dominated by a single coherent and elegant paradigm might provide the requisite circumstances.[9] But in such cases it might be wondered whether these specialties can be really said to require appreciable creativity in the first place.

Conclusion

In light of this documentation and discussion, I believe that the case for Campbell's (1960) blind-variation and selective-retention model of creativity is stronger than ever before. I am even of the opinion that there is something very natural about applying the Darwinian perspective to creativity. This opinion arises from the very definition of creativity, which is traditionally said to entail the production of some entity that is simultaneously both original and adaptive. By this definition, of course, biological evolution by natural selection is also creative. Genetic recombination and mutation yields a varied assortment of original genotypes. This genotypical variation is subsequently subjected to natural selection, which then determines the variations that are best adapted to the prevailing environmental conditions. The creative individual, too, produces original ideas, which are then subjected to first cognitive and then sociocultural selection, retaining solely those ideas that are adaptive by some criteria of utility, truth, or beauty. And, of course, an original idea is one with a low a priori probability, which suggests that such ideas must mostly emerge from a blind-variation process.

Indeed, I would like to go one step further and argue not only that the Darwinian perspective on creativity seems the most natural but also that the overall creative process must be inherently Darwinian. My point of departure for this extreme statement is the simple observation that the human brain is unbelievably complex. It has more than one modality with which to contemplate the world, including visual, auditory, and kinesthetic (see, e.g., Hadamard, 1945). Images may be concrete or abstract, linguistic or nonverbal (Roe, 1952). Memories may be encoded multiple ways, and knowledge may be learned by either explicit or implicit mechanisms (Reber, 1993). Not only may the two hemispheres process information in distinct manners, but additionally there may exist other alternative information systems (Epstein, 1994). Logic and intuition, sensation and feeling, volition and passivity—these all dwell in the same head. No wonder, then, that the number of rival theories of creativity is quite large, even overwhelming. The psychoanalysts, the Gestalt and humanistic psychologists, the behaviorists, and the cognitive scientists all have their separate opinions about how creativity works. Although the Darwinian model then just seems another rival explanation added to the pile, in actual fact this perspective might be placed at the very apex of the heap. For the variation-selection process may subsume all the alternative accounts as special cases of the more general process.

We need only assume that everyone is right and that all hypothesized mechanisms and processes can effectively operate on at least some occasions. Sometimes deliberate, conscious thought may work best, whereas other times intuition may be the most workable strategy. Some problems may be best solved by finding a visual representation, whereas others may be better treated using verbal or mathematical representations. Certain times the individual may have to regress to more infantile ways of thinking about the world, but other times such autism may lead nowhere. And so forth. When the human mind then finds itself confronted with a truly novel or complex problem, previous problem-solving experiences will reach a point that they can no longer provide a priori guidance regarding the best line of attack. As a result, the full array of potential strategies may be evoked, and then tried and tested in a more or less chaotic fashion. In a sense, each rival theory of the creative process becomes a "metavariation," where each metavariation is given the chance to solve the problem at hand. This largely blind application of alternative problem-solving approaches is itself Darwinian even if a specific approach attempted is not Darwinian. Because the variation-selection model can encompass such a diversity of processes, at some profound level creativity must be Darwinian. In both cultural and biological evolution, it may constitute the single most important explanation for creative innovations.

Admittedly, some critics may view this very inclusiveness as a fault rather than as a virtue. Darwinian theories sometimes seem little more than compilations of "just-so stories" in which explanatory breadth is purchased at the expense of predictive precision and empirical testability (Rose & Lauder, 1996). A theory that explains everything may ultimately explain nothing. In other words, Campbell's model of creativity may lack the falsifiability that Popper (1959) argued was the hallmark of genuine science. This criticism is not without at least some justification. In certain respects all Darwinian theories, both primary and secondary, do indeed suffer from the same difficulty. Darwin's own theory of evolution by natural selection, for example, does not lead to the same kind of decisive

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[9] Even this small concession may be yielding too much ground. Cole (1983) provided ample evidence that the diverse scientific disciplines do not differ substantially in the magnitude of consensus. For all sciences, moreover, the standards for judging research are so vague and imprecise that it is virtually impossible for even experts to judge the long-term success of a given project. For example, the ratings journal reviewers give submitted manuscripts do not predict the citations the articles receive when published, nor do the priority scores given grant proposals predict the later impact of funded or unfunded projects (see Cole, 1983, for review). If experts cannot predict the long-term worth of contemporary research conducted by colleagues, it is highly unlikely that they can do a better job anticipating the ultimate impact of their own investigations.

predictions as does Newton's gravitational theory or Einstein's relativity theory. Instead, it provides a general explanatory structure for understanding a tremendous diversity of biological phenomena. By the same token, Campbell's (1960) theory by itself does not support the immediate derivation of critical empirical tests.[10] Instead, it offers a broad interpretative framework for coordinating a tremendous amount of data about various aspects of creative phenomena.

On the other hand, Darwin's theory does much more than provide a broad explanatory scaffolding; it also constitutes the very foundation for more specific theories that enjoy impressive predictive powers, such as the mathematical models of population genetics (e.g., Fisher, 1930). Although the predictions generated by these lower order systems cannot be taken as critical tests of the larger framework, these straightforward applications establish the scientific fruitfulness of the Darwinian research program (Lakatos, 1978). It has the crucial capacity to inspire investigations into natural phenomena that would be either misunderstood or ignored. The same principle applies to Campbell's theory of creativity. Although the theory itself does not explicitly imply any up–down tests, it does inspire the conception of more specialized models that do feature this desired capacity (e.g., Martindale, 1990; Simonton, 1988e, 1997a). To the extent that these various submodels survive empirical scrutiny, they lend further support to the broader theoretical system of which they are a part.

For living creatures, primary Darwinian theory provides the most far-reaching explanatory network. As the famous evolutionary biologist Theodosius Dobzhansky once put it, "nothing in biology makes sense except in the light of evolution" (quoted in Sober, 1994, p. 490). Furthermore, from Galton (1869) and James (1880) to the present day (e.g., Barkow, Cosmides, & Tooby, 1992; Buss, 1995), many psychologists have affirmed that evolutionary theory offers the best starting place for a comprehensive theoretical account of human cognition and behavior. At the same time, I have argued here that secondary Darwinian theory, as proposed by Campbell (1960), furnishes the most complete basis for comprehending human creativity. These two statements may someday become logically and empirically integrated. That is, Campbell's secondary Darwinian model of creativity may be eventually subsumed under primary Darwinian theory. In fact, initial efforts have already been made in this direction (Eysenck, 1995; Simonton, 1999a). For example, G. F. Miller (1997, 1998) recently explicitly showed how Campbell's model may be explicated in terms of the evolution of adaptive unpredictability, especially under the selection pressures of courtship and intraspecies competition (see also Darwin, 1871/1952; Hammer & Zubin, 1968). If these extensions of primary Darwinism eventually succeed, Campbell's model of creativity will acquire even greater theoretical justification (Wilson, 1998). It will become the theory most consistent with the most impressive explanatory system in the psychological sciences.

Note

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[10] To be sure, the Darwinian theory makes the specific prediction that it should be impossible to program computers to simulate true human creativity without the incorporation of a blind-variation mechanism (where the simulation would include all core aspects of the phenomenon and not just the creation of a single representative product). Nevertheless, this prediction will probably not be falsifiable until computer models can pass Turing tests that require the simulation of more everyday human behaviors.

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