1 The chance-configuration theory

The psychology of science

With the launching of the Soviet sputnik into space, American psychologists were alerted to the urgency of enlarging our understanding of scientific creativity. J. P. Guilford, in his 1950 Presidential Address before the American Psychological Association, had already called for closer attention to the study of creativity, but current events injected this need with more significance (Golovin 1963). About this time the National Science Foundation sponsored a series of conferences, "The Identification of Creative Scientific Talent," at the University of Utah, the central papers of which were published in the 1963 volume *Scientific Creativity: Its Recognition and Development,* edited by Calvin W. Taylor and Frank Barron. We thus had every reason to believe that the discipline was on the threshold of a respectable "psychology of science," the first comprehensive science of science (see also Maslow 1966; Stevens 1939). But matters progressed little further, and the concerted effort largely petered out within a decade (Singer 1971). By the time that the psychology of science had, for all practical purposes, vanished as a distinct field of inquiry, the sociology of science had taken wing as a scholarly enterprise, joining the already high-flying disciplines of the philosophy of science and the history of science. There were accordingly three "metasciences" dedicated to the scholarly examination of science, two of these humanistic and only one scientific in analytical emphasis – with psychology patently excluded (see Houts 1988). This is not to say that psychologists ignored the subject altogether but only that any efforts were sporadic, inconsequential, or noncumulative (Fisch 1977). Many psychological studies were oriented more toward idiographic case studies than toward the abstraction of nomothetic principles that govern scientific discovery and invention (cf. Simonton 1983c). General laws were applied to specific instances rather than adducing those generalizations from multiple particulars. Howard Gruber's *Darwin on Man* (1974) may illustrate this approach at its best.

Nonetheless, in the past few years several psychologists have come to the realization, however delayed, that when opportunity had knocked at the door, the discipline was found asleep. Psychological processes permeate all scientific activities, and this is particularly true in regard to creativity and problem solving. The recent coming of age of the cognitive sciences perhaps accelerated the dawning awareness that psychology may have something to contribute beyond what had already been offered by sociology, philosophy, and the history of science (see Faust 1984). In any event, psychologists have again received invitations to attend conferences devoted to the examination of science, especially the study of scientific creativity. Articles by psychologists have become more common in professional journals, including the interdisciplinary journals specializing in science studies, such as *Scientometrics* and *Social Studies of Science*. And books are once again concentrating on the psychological aspects of science (e.g., Faust 1984; Gholson, Houts, Neimeyer, & Shadish 1988; Jackson & Rushton 1987; Mansfield & Busse 1981; Tweney, Doherty, & Mynatt 1981). It is always dangerous to engage in prophecy, yet it seems that this growing movement may constitute a renaissance of that very psychology of science whose development was arrested two decades ago. At this moment in this miniature narrative, I as an investigator enter the story.

Over the past dozen years or so I have been engaged in research on exceptional personal influence. That is, I have been interested in determining why certain individuals have an inordinate and enduring impact on others in a given domain of achievement. For the most part, although not exclusively, this compelling interest has taken the form of historiometric studies of "geniuses" – of eminent creators and leaders – with much of this work focusing on scientific creativity. Some of the greatest geniuses in science – like Aristotle, Newton, and Einstein – exerted a tremendous and long-term influence not only on their scientific colleagues but on the general intellectual community besides. I have endeavored to understand the personal and social basis for such monumental impact, concentrating especially on the connection between age and achievement, the consequences of political conditions, and the role of the zeitgeist in the generation and acceptance of discoveries and inventions.

In addition to my own empirical and theoretical labors, I have tried to keep abreast of the vast literature on genius, in general, and scientific creativity, in particular. During this research and reading, I have spotted what I consider a consistent theme pervading the phenomenon of outstanding scientific discovery and invention. This theme expanded first into some empirical hypotheses and now can be developed into a full-fledged psychological theory. I style this explanatory and predictive framework the *chance-configuration theory*. This conception, I maintain, facilitates both the organization of past research findings and the formation of new research hypotheses regarding scientific creativity.

I shall begin by sketching the chief tenets of the chance-configuration theory. This chapter will conclude by outlining what I consider to be the theory's explanatory scope. The remainder of this book is largely devoted to an empirical development of the basic ideas presented in this chapter – their enlargement into a comprehensive interpretation of exceptional scientific creativity.

The theory

At the most superficial level, there is little if anything original about the chance-configuration theory. I have always been impressed with Darwin's theory of evolution by natural selection and have often been fascinated with attempts to apply Darwinian ideas to innovation and sociocultural change. In particular, my own theoretical outlook can be said to have roots in Donald Campbell's (1960) blind-variation and selective-retention model of creative thought. To some degree, the current theory is an elaboration, albeit with a shift in nomenclature, of Campbell's ideas – ideas that were recently identified as holding "promise as a possible integrative framework for the psychology of science" (Tweney et al. 1980, p. 405). I shall outline those aspects of Campbell's model that I find most useful before I present my own rendition.

Campbell's scheme purports to be rather general, applicable to virtually any variety of knowledge acquisition or environmental adaptation, including biological evolution by natural selection, trial-and-error learning, creative thought, and social evolution (Campbell 1960, 1965). Furthermore, the model has provided the basis for his "evolutionary epistemology" (Campbell 1974a), a descriptive theory of knowledge that has certain affinities with Karl Popper's philosophy of science (see Schlipp 1974). Although I am in essential sympathy with all of these developments, we need to discuss only that portion of Campbell's thinking that deals specifically with the creative process and the growth of scientific knowledge. For our purposes, then, Campbell's position may be summarized as the following three core propositions:

1. The acquisition of new knowledge, the solution of novel problems, requires some means of producing *variation*. Campbell argues that this variation, to be truly effective, must be fully blind. To count as "blind" the variations must be unrelated to the environmental conditions, including the specific problem, under which the variations are generated, and the varia-

tions should be unrelated to one another (i.e., feedback from the failure of one variation is not used to formulate the next variation in a series of trials) (Campbell 1960). To the extent that the variations are shaped by the environment, whether past or present, they cannot be considered blind. Of course, many alternative qualifiers might be placed on the variations, such as chance, random, aleatory, fortuitous, and haphazard (Campbell 1974b, p. 147), but Campbell preferred the designation blind, for it retains the notion that the variations do not use any information already given, while at the same time it does not commit the variations to a particular generation mechanism. However, within the specific confines of creativity, I prefer the adjective *chance,* as will become evident later in this chapter.

2. These heterogeneous variations are subjected to a consistent *selection* process that winnows out all but those that exhibit adaptive fit (Campbell 1960). In other words, there must exist somewhat stable criteria by which those variations that offer viable solutions to the problem at hand are separated from those that embody no advance and hence are useless. In Darwinian evolution just such a selection procedure is the cornerstone of the theory: Natural selection chooses those genetic variations (whether chance mutations or random assortments of genes) that favor the fit between organism and environment. In scientific discovery, too, variations are judged against a set of criteria; those variations that fail to meet these requirements are weeded out from the body of scientific knowledge.

3. The variations that have been selected must be preserved and reproduced by some mechanism; without such *retention* a successful variation cannot represent a permanent contribution to adaptive fitness. The chromosomes retain fit variations in biological evolution; memory preserves knowledge acquired through learning; and cultural transmission through socialization and education saves valuable customs and techniques in sociocultural evolution.

Campbell noted the fundamental contradiction between the first and third propositions: Blind variation implies a departure from retained knowledge. A genetic mutation is a shot in the dark that ignores the wisdom contained in parental chromosomes, and thus mutant genes are often lethal; an excessive mutation rate would spell the extinction of a species. At the same time, however, a gene pool totally lacking in variation would be unable to adapt to changing circumstances, with consequences just as fatal to the species' survival; in time the genetically encoded wisdom would convert to foolishness. A comparable process operates on the level of the creative process. Any society has a rich repertoire of skills and concepts that enable its members to survive and prosper, and accordingly the cross-generational preservation and transmission of these adaptive features are a high priority. But without any provision for variation, for creativity, the sociocultural system will eventually stagnate, lose adaptive advantages, and in the end be defeated in the competition with rival systems. In a sense, there is an intrinsic contradiction between preserving the fruits of past creative acts and sowing the seeds for future creative achievements. In regard to scientific creativity, Thomas Kuhn (1963, p. 343) referred to this conflict as an "essential tension," for "very often the successful scientist must simultaneously display the characteristics of the traditionalist and of the iconoclast."

Frequently the solution to this conflict is to place restrictions on the variations, limitations that use a priori or a posteriori information. Most biological variation is limited to recombinations of genes of proven environmental utility, and even then not all combinations are permitted. In trial-and-error learning, not all potential behavior patterns are attempted but, rather, merely a subset that has proved itself useful in the past experience of the species and the individual. Cultural variations, too, are normally not allowed to run rampant; certain types of behavioral combinations, in fact, are outright proscribed as criminal or insane. Consequently, many variations display some "insight" into narrowing the possible trials from the near infinity of conceivable alterations. In any event, in chapter 5 we shall see that the essential tension between variation and retention helps explain why success as a scientist is so often a curvilinear, concave-downward function of key developmental variables. Creative development requires a well-adjusted trade-off between the traditionalist and iconoclast dispositions (Simonton 1987a,c).

Campbell (1960) was willing to admit that his model had been anticipated by many thinkers before him, the latter half of the 19th century being particularly resplendent with philosophers who felt the influence of Darwin's revolutionary ideas. He cited, among many examples, the 1880 essay, "Great Men, Great Thoughts, and the Environment," by William James, which emphatically states that "the relation of the visible environment to the great man is in the main exactly what it is to the 'variation' in the Darwinian philosophy" (p. 445). In particular,

> the 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, adopts or rejects, preserves or destroys–*selects,* in short, just as it selects morphological and social variations due to molecular accidents of an analogous sort. (p. 456)

Even though these quotations require qualification to be palatable to modern ears, they do illustrate how Darwinian ideas might be extrapolated to creative behavior. Indeed, if anything, the analogy between biological and other forms of evolution or development has been treated too often and taken too seriously over the past century or so – from Herbert Spencer to the present day.

I consequently should emphasize that I do not wish to draw detailed correspondences among various knowledge–acquisition processes. There are many ways that the analogy between biological and sociocultural evolution breaks down, and human information processing, which constitutes a form of individual development, has its own characteristics as well (Campbell 1965, 1986). Even so, the three components of variation, selection, and retention unite all varieties of knowledge acquisition under a single generic form. The chance-configuration theory offered in the following sections clearly falls into this broad class, too. The key ideas of this theory are (1) the chance permutation of mental elements, (2) the formation of configurations, and (3) the communication, social acceptance, and sociocultural preservation of those configurations. It will become evident that I am here offering a truly social-psychological theory of scientific creativity, one that emphasizes both intrapsychic events taking place solely within the individual and interpsychic or interpersonal events depending on social communication and interaction.

Chance permutations

We shall begin with the assumption that the creative process entails operations on what I choose to call *mental elements*. These psychological entities are the fundamental units that can be manipulated in some manner, such as the sensations that we decide to attend to, the emotions that we experience, and the diverse cognitive schemata, ideas, concepts, or recollections that we can retrieve from long-term memory. In scientific creativity, the predominant mental elements are cognitions of some kind, such as facts, principles, relations, rules, laws, formulae, and images. Yet immediate sensations may also play a role in laboratory experimentation and field exploration, and feelings may figure in scientific thought and discourse as well (Mahoney 1976). Sometimes these mental elements can be evoked voluntarily (e.g., the deliberate retrieval of a stored fact from memory); at other times these elements enter mental processing involuntarily (e.g., via a conditioned emotional association). Moreover, these mental elements do not have to be fully conscious, but rather, many enter information processing at the periphery of consciousness. As Einstein observed, what we "call full consciousness is a limit case which can never be fully accomplished" because of the inherent "narrowness of consciousness" (quoted in Hadamard 1945, p. 143).

Whether voluntary or involuntary, conscious or unconscious, these mental elements must be free to enter into various combinations. In fact, according to the theory proposed here, the fundamental generating mechanism in scientific creativity involves the *chance permutation* of these elements. To clarify what I mean, let me start with the term *permutation.* I favor this term over the alternative more often employed, namely, *combination.* In probability theory, combinations are sets of elements that have no particular order, whereas for permutations the elements' order in the sets is critical to distinguishing among sets. In actual applications, the combinations are frequently more interesting than are the permutations. When calculating the odds of being dealt a royal flush in a card game, for example, the order in which one acquires the ace, king, queen, jack, and ten is immaterial to the chances of obtaining a winning hand. Nonetheless, in other applications the specific order of the elements is crucial, requiring that any given generic combination be separated into its specific permutations. As a case in point, "a mathematical demonstration is not a simple juxtaposition of syllogisms, it is syllogisms *placed in a certain order,* and the order in which these elements are placed is much more important than the elements themselves" (Poincaré 1921, p. 385). This distinction will become useful later in chapter 6 when we discuss the phenomenon of multiple discovery. Consequently, the term permutation is retained insofar as it connotes that we must discriminate among combinations that, although containing identical elements, differ in how those elements are arranged. This usage permits us to say that a combination can form two or more permutations with the same elements but with the elements assigned distinctive levels of importance or emphasis within each permutation.

The hard part is to define *chance.* In general, to claim that the permutations are generated by chance is equivalent to saying that each mental element is evoked by a myriad determinants, there being virtually no overlap in the determinants for any pair of elements defining a given permutation. Chance, after all, is a measure of ignorance, a gauge of the situation in which the number of causes is so immense as to defy identification. Though chance implies unpredictability, it does not necessitate total randomness. We do not need to argue that all permutations of a specific set of elements are equiprobable, in contrast with Mendelian genetics. We must merely insist that a large number of potential permutations exist, all with comparably low but nonzero probabilities. Later in chapter 3, when I relate the theory to the cognitive style of creative persons, I shall describe how chance permutations can come about, at that time drawing on a model originally proposed to explain intuitive thought processes (Simonton 1980a).

Configuration formation

At this point we have evidently postulated a process that yields variations. We next must introduce some principle of selection into the theory, for not all chance permutations can or should be retained. In the case of scientific creativity, selection mechanisms operate on both personal and social levels. At this stage in the argument let us focus on one personal, or intrapsychic, criterion: Here we propose that the primary selection procedure is predicated on the fact that chance permutations vary appreciably in *stability*. On one extreme are transitory juxtapositions of mental elements that lack sufficient coherence to form a stable permutation, so that the permutation process usually continues with little or no pause. These unstable permutations we may call mental *aggregates*. On the other extreme are permutations whose elements, though brought together by a chance confluence of multiple determinants, seem to hang together in a stable arrangement or patterned whole of interrelated parts. These stable permutations I label *configurations*. It must be stressed that aggregates and configurations are permutations of mental elements that fall along a continuum from the highly unstable to the highly stable, with many gradations between. Nonetheless, we assume that of the innumerable chance permutations, only the most stable are retained for further information processing, for the greater the stability is, the higher the probability of selection will be. Further, on a subjective plane, the more stable a permutation is, the more attention it will command in consciousness, as the unstable permutations are too fleeting to rise often above unconscious levels of processing. Thus, configurations of elements are selected out from the permutations to be saved for further conscious deliberation.

The crucial requirement, then, is to define *configuration*. I chose this word advisedly, over the many possible alternatives (schemata, associative fields, constructs, concepts, ideas, matrices, etc.), based on its etymology and common applications. The root of *configuration* is a Latin word meaning "to shape after some pattern." A configuration is thus a conformation or structural arrangement of entities and implies that the relative disposition of these entities is central to the configuration's identity. In chemistry and physics the relative spatial location of atoms in a molecule is often called a configuration. Likewise in astronomy the characteristic grouping of heavenly bodies is sometimes referred to as a configuration. Finally, in psychology and, most particularly, in Gestalt theory, a configuration is a collection of sensations, emotions, motor patterns, and concepts organized in such fashion that the collection operates as a unit in thought and behavior. Indeed, if a configuration becomes sufficiently refined, it can become a new mental element that can enter into further permutations. That is, if the diverse elements that make up the configuration become strongly connected, they all will become "chunked" so that they function as a single element, taking up less space in limited attention. This process of consolidation is analogous to that when the atoms forming a molecule become subordinate to that molecule, which then operates as a unit in physical transformations (e.g., Avogadro's number applies to molecules of gas, not to the separate atoms).

It may seem contradictory to assert that mental elements thrown together by happenstance can unite in a way that prevents disintegration, but we must recognize that what jumbles the elements together is different from what glues them together. The elements themselves contain properties that will determine how well they fit together. The intrinsic attributes of one element may dovetail nicely with other elements, creating a stable unit. Hence, even if two elements are tossed together by haphazard juxtaposition, those elements may stick together because of mutually compatible properties. This event is analogous to a chance encounter that brings two people together who then form a lasting relationship on the basis of similar and complementary interests and values. Or to offer an analogy from chemistry, the hundred or so chemical elements each have characteristics, principally valence, that decide how they will behave in chemical reactions. For example, an atom of sodium tends to give up an electron in order to acquire a complete outer electron shell, whereas chlorine, because it lacks only one electron to finish out its outer shell, tends to take up an electron. Thus, sodium and chlorine atoms are intrinsically compatible elements, the former yielding an electron to the latter so that both can form a stable "molecule" of sodium chloride (Na^+Cl^-). Therefore, the random impact of gaseous chlorine on solid sodium will corrode the metal into sodium chloride. On the other hand, helium, which already possesses a full outer shell and thus is placed in the column of inert elements on the periodic table, will not combine with either sodium or chlorine, no matter how many random impacts are permitted between the molecules.

Because certain elements have intrinsic affinities for each other, not only can a chance linkage of two elements produce a stable pairing, but large clusters of elements also can spontaneously form highly ordered arrangements out of chaos. Campbell (1974b) offered a striking example of crystal formation, in which under the proper conditions, a dissolved chemical will not precipitate into merely amorphous aggregates but, rather, fine crystals.

A specific crystalline structure is implicit in the ions or molecules leaving solution, and so a more organized spatial pattern is actually more stable than is one less organized, yielding a specific configuration from the mere random collisions of the ions or molecules.

To be sure, this last example is much simpler than what occurs in intellectual matters. It is not always apparent when two distinct mental elements contain a natural affinity, nor is it obvious how these affinities might lead to larger structures, or configurations. At least, such ideational compatibilities are less apparent on a priori grounds and are, rather, discerned retrospectively, on a post hoc basis. For instance, a number of studies have illustrated how specific combinations of philosophical beliefs have been more prone to appear than have others in Western civilization (Simonton 1976c,f). Nominalism, as a case in point, is more likely to be associated with empiricism, mechanistic determinism, and the doctrine of incessant change than with mysticism, monistic idealism, and eternalism, just as hedonistic and utilitarian ethics display a stronger a posteriori linkage with mechanistic materialism, nominalism, and extreme individualism than with monistic idealism, realism, and universalism or statism. Even if some were to argue that these affinities could be justified a priori (see, e.g., Sorokin 1937–1941), such arguments would be precarious at best. As is well known, Kant erred in holding that Euclidean geometry was true a priori, a belief dispelled with the advent of perfectly consistent non-Euclidean geometries that later became the foundation for Einstein's treatment of space in his general relativity theory.

Configuration acquisition. To appreciate how chance permutations may generate stable collections of elements, we first must note that very few configurations arise in this way. On the contrary, most configurations consist of mental elements that have been connected on either empirical or logical grounds. In particular, these mental givens that provide the material for chance configurations are of two types, a posteriori and a priori configurations (cf. Stevens 1939).

A posteriori configurations establish a correspondence between perceived events and their cognitive representations. If, for example, we have a set of world events $A_1, A_2, \ldots, A_n$ represented by a set of mental elements A'_1, $A'_2, \ldots, A'_n$ and if, in reality, the conditional probability of any one event given any one of the others is much greater than zero, so that $p(A_i/A_j) \gg 0$ for all $i \neq j$, we can expect the mental elements to be ordered so that the subjective association strengths approximate the objective conditional probabilities (e.g., the rank order of conditional probabilities positively correlates with the rank order of association strengths). That is, in some