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Book Review

The End of Certainty: Time, Chaos, and the New Laws of Nature. Ilya Prigogine. New York: Free Press, 1997. Pp. viii + 228.

Between a worldview that is purely deterministic, and a worldview governed by randomness, this book identifies a "narrow path" which allows us to recognize the element of coincidence in a world that can nevertheless be known, understood, and to some degree predicted. This narrow path shields us from the state of ignorance that a universe governed by randomness would bring, as well as from the unwarranted certainties a deterministic worldview appears to offer with respect to the predictability of phenomena. The challenge to a purely deterministic view of science, as discussed in this book, is very old. The Greek philosopher Epicurus (341–270 B.C.) was disturbed by the then-prevailing paradigm about the movement of atoms, which argued that their trajectories ran a parallel course through a void. This theory did not allow atoms to collide, nor did it allow for an element of unpredictability in their movements. The dilemma posed by this scenario, according to Epicurus, is that in a world made up of the fully predictable movements of atoms, human Free Will becomes an oxymoron, because the future will be fully predetermined. Furthermore, Epicurus argued that in a world where outcomes can be fully predicted, there is no need to appeal to the good will of the Deities to change the course of events in our favor.

William James disputed this conceptualization of the difference between freedom and predictability as far as psychology is concerned. He noted that "however closely psychical changes may conform to law, it is safe to say that individual histories and biographies will never be written in advance no matter how "evolved" psychology may become" (James, 1983/1890; p. 1179). The fact that psychological processes may follow predictable patterns does not require us to assume that the behavior of individuals is fully determined in advance, nor that individuals are deprived of their freedom. While this conclusion may sound reassuring, the debate about determinism has continued to play a significant role in psychology. The "nature versus nurture" debate is an example. "Nature versus nurture"

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concerns the use of twin comparisons to demonstrate a genetic basis for psychological outcomes such as intelligence, personality, and mental illness. The traditional way to interpret similarities of those characteristics amongst twins (identical twins in particular) is as an indicator of their hereditary origin. The implication of such findings is that those psychological traits whose heritability is demonstrated cannot be changed through psychological or educational interventions such as therapy or instruction (i.e., the genetic determinism of behavior). One of the criticisms of this deterministic interpretation of findings is that it impairs parents' and schoolteachers' sense of their own effectiveness in favorably affecting the development, education, and growth of their children (Baumrind, 1993). This criticism runs along the same lines as Epicurus' argument concerning human freedom in a deterministic world.

Epicurus resolved the unsettling state of affairs he encountered by proposing that particles could deviate slightly from their course, at uncertain times, and uncertain places. This solution brings an element of uncertainty into our understanding of the world around us, of the behavior of particles in particular, and this element of unpredictability safeguards human liberty. Epicurus' dilemma foreshadows much of the discussion in this book about the place of unpredictability in science, in physics in particular. Prigogine, in *The End of Certainty,* discusses unpredictability both on the microlevel (movement of particles), and on the macrolevel (evolution of the universe.) There are reasons, other than the preservation of human freedom, to be interested in the influence of randomness on the course of things. Chaos theory argues that in order to understand qualitative transformations in the self-regulatory behavior of systems, we are required to include a random component into our predictive models. The focus of the discussion in this book is on irreversibility (time), randomness (uncertainty), and the connection between the two.

In psychology, our interest in randomness is typically, but not necessarily, limited to the uncertainty associated with procedures of empirical confirmation (i.e., generalization from a random sample to the population from which the sample was drawn). Complexity theory is interested in randomness as an inherent quality of the phenomena we observe. Randomness as an inherent systemic quality still requires a statistical description, however, and a significant part of this book is devoted to the question how to do this. It is often unrealistic to measure discrepancies from equilibrium on the basis of individual observations. Aggregation of measurements over larger time chunks, or regions of the phase space, allows one to examine the degree of variability in observations, and infer the distance from equilibrium from these aggregated findings (a procedure called "coarse graining"). The need for a statistical treatment of data is also illustrated by the fact that we measure degrees of disorder in terms of the exponential separation of trajectories in phase space (Lyapunov exponents).

Deterministic and time-reversible models assume that once we know the initial conditions of a system, subsequent states as well as preceding states can be calculated. This symmetrical assumption about the passage of time is problematic, however, because changes over time are not necessarily be reversible. This book discusses the origins of Nonlinear Dynamical Systems (NDS) thinking and the challenge it poses in physics to Newton's laws of nature, which are deterministic and time-reversible. Science, in this conception, provides the means to predict the future, and to recover the past. The second law of thermodynamics, on the other hand, states that entropy strives for a maximum in isolated systems. This law challenges traditional assumptions of time reversibility. The progression toward maximum entropy in closed systems implies time irreversibility: i.e., the "arrow of time" points toward disorder, and cannot be turned in the opposite direction.

In nonequilibrium physics, new forms of coherence can emerge through bifurcations. Irreversible processes, in this conceptualization, are associated with a qualitative change toward order, rather than a gradual change toward disorder. There is a probabilistic element in the qualitative changes described by far-from-equilibrium models: the choice of new attractors, when a system is in an unstable state, is by definition unpredictable. The notions of probability and irreversibility are therefore very closely connected. One cannot "un-bifurcate" two attractors to bring back the original stable state of a system.

Nonlinear dynamical systems (NDS) theory is designed to handle irreversible processes of this kind, and to describe the role of randomness in producing qualitative change. This book outlines contemporary systems science by describing how chemistry and physics have evolved over time, and how contemporary NDS challenges conventional notions of how the world works. As in *Order out of Chaos* (Prigogine & Stengers, 1984), Prigogine describes the progression of ideas in physics over time to illustrate the need for NDS models. As far as Prigogine's written work is concerned, this book can best be seen as an extension of Book Three from *Order out of Chaos,* which is also concerned with randomness and irreversibility, and the direction of the passage of time. In terms of content, the two works partly overlap, but this book provides more detailed examples, and offers a more specific discussion of the applicability of the principles of randomness and irreversibility in physics. The current book also further elaborates on the connections between nonequilibrium physics and established doctrines such as relativity theory and Big Bang theory. Like *Order Out Of Chaos* this book fruitfully considers some other aspects of change and randomness, such as the production and destruction of correlations between particles in unstable systems, systemic fragmentation (Baker transformation), and the sensitivity to initial conditions that characterizes chaotic systems.

The relevance of principles such as these for psychology lies in their challenge to the tacit assumption of stability that characterizes the way psychologists tend to think about their work. To infer a correlation between variables in the behavior of a particular individual on the basis of a correlation between those variables in a sample requires us to make unwarranted assumptions with respect to the level of systemic stability. For example, we know that the behavior of children and adolescents is embedded in their family systems. If the family system is highly unstable, as family systems often are, measurements concerning the child's behavior may fluctuate dramatically, and its correlation with other variables may not be consistently present. Dynamical notions about the stability of research findings challenge our tendency in psychology to rely on cross-sectional measurements, or on longitudinal assessment with large time intervals. The challenges of NDS to physics and psychology are essentially not different.

The connection between randomness and irreversibility, as discussed in this book, also directly applies to psychology and other life sciences. Growth, maturation, and learning are examples of processes where the arrow of time can meaningfully projected in only one direction. While one could argue that learning is characterized as a progression toward increasing complexity, there are also bifurcations, which reduce complexity through qualitative transformation of the system. For example, the problem solving of children undergoes qualitative transitions aimed at simplification. If children use their fingers to compute additions and subtractions, this approach will become very complicated when the numbers become too large. To make a cognitive shift from a concrete to an abstract representation of quantities simplifies the problem solving process. This qualitative shift typically goes from concrete to abstract, and not back to concrete. Human aging can, unfortunately perhaps, also be seen as an example of irreversibility.

The dynamical description of qualitative transformations also brings into focus another crucial point of difference between traditional scholarship and its dynamical alternatives. The process of change itself is the typically the target of inquiry rather than the outcomes of those changes. Prigogine refers to this shift as "From being to becoming." In some social sciences, dynamical approaches have typically been grounded in phenomenology and hermeneutics, which share the ontological emphasis on process. The dynamical component in psychology has traditionally been relegated to psychoanalysis, and its offshoots. Since the nineteen-fifties, there has also been significant research into the dynamics of families, small groups, and organizations, research, which considers the process of change as a central concern. The study of change has been of interest to evaluation researchers who are concerned with the effectiveness of various psychological and educational interventions, such as psychotherapy and remedial teaching.

Prigogine's explicit intention in this book is to allow the chaos framework to reach beyond the confinements of a single discipline. While most of the discussion focuses on the behavior of particles in physics and chemistry, much of this work can be used as a blueprint for a more dynamical approach in other areas of knowledge. This book illustrates how nonlinear dynamical principles have transformed the field of physics, and challenged some of its conceptual foundations. As a result of these developments, we have also come to better understand a wide array of psychological phenomena. For example, to chaos theory we owe a better understanding of role of communication and information exchange in collective adaptation and problem solving. We also better understand how growth of the human body contributes to how children learn to walk. We are better able to appreciate the role of randomness in the development of novel thoughts and ideas, and we now better understand the origins of structural change in families and organizations. We have also come to better appreciate the dynamical underpinnings of learning, and of human speech perception and production. The contribution of chaos theory in these areas of knowledge is as significant as it is irreversible.

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