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Unpredictability and Indeterminism in Human Behavior:

Arguments and Implications for Educational Research

GARY A. CZIKO

This essay presents arguments for the view that complex human behavior of the type that interests educational researchers is by its nature unpredictable if not indeterminate, a view that raises serious questions about the validity of a quantitative, experimental, positivist approach to educational research. The arguments are based on (a) individual differences, (b) chaos, (c) the evolutionary nature of learning and development, (d) the role of consciousness and free will in human behavior, and (e) the implications of quantum mechanics. Consequently it is argued that educational research that attempts to predict and control educational outcomes cannot be successful and that educational research should focus on providing descriptions and interpretations of educational phenomena to provide findings that can be used to improve our understanding of learning, development, and education and to facilitate their evolution.

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Asked to find a recurring theme in the issues of *Educational Researcher* from the late 1970s and throughout the 1980s, one would have little difficulty discovering a continuing preoccupation and debate concerning the epistemology of educational research. This debate, centered on issues related to quantitative versus qualitative approaches to research, has at the very least raised serious questions about the quantitative, experimental, positivist approach to educational research, an approach that nevertheless continues to dominate mainstream educational research.

There appears, however, to have been little discussion among educational researchers of what may be an even more basic issue, that is, the possibility that the phenomena studied in the social and behavioral sciences are essentially unpredictable and indeterminate. This essay presents five arguments for the unpredictability and indeterminacy of complex human behavior of the type of interest to educators and educational researchers (hereafter referred to simply as "behavior") and begins a discussion of the implications for educational research.

Arguments for the Unpredictability of Human Behavior

Arguments From a Deterministic Perspective

The first two arguments to be considered for the unpredictability of human behavior are presented within a deterministic perspective. It is argued that even if we do inhabit a completely deterministic universe, there are nonetheless compelling reasons to believe that it is impossible to make accurate, nontrivial predictions concerning human behavior.

Individual differences. Probably the best-known argument for limits on the predictability of human behavior within educational contexts is that of Lee J. Cronbach and Richard Snow. Cronbach and Snow (Cronbach 1975, 1982; Cronbach & Snow, 1977; Snow, 1977) have argued that individual differences interact with educational treatments in such a way that, for example, whereas Method A might be the most effective way to teach a child of Type 1 to learn to read, this same method might be quite ineffective for teaching another child of Type 2 for whom a much better method is Method B. These aptitude-treatment interactions (ATI) may themselves interact with other factors such as time so that in 10 years' time Method 1 may become less effective for teaching Type 1 children and become better suited to Type 2 children (an aptitude by treatment by time interaction).

Considering the complexity of the constantly changing interacting factors influencing human behavior, Cronbach and Snow conclude that comprehensive and definitive experiments in the social sciences are not possible and that the most we can ever realistically hope to achieve in educational research is not prediction and control but rather only temporary understanding. It is important to point out that in taking this position Cronbach does not consider human behavior unlawful and unpredictable in itself but rather that the interacting nature of aptitude, treatment, and time variables means

that we cannot store up generalizations and constructs for ultimate assembly into a network. It is as if we needed a gross of dry cells to power an engine, and could only make one a month. The energy would leak out of the first cells before we had half the battery completed. (1975, p. 123)

Recently, Phillips (1987) has taken exception to Cronbach and Snow's pessimistic view of educational research in arguing that research in the social sciences is not fundamentally different from research in the physical sciences. First, Phillips contends that complex interactions also occur in the physical sciences where, for example, "pressure and volume interact to affect the behavior of a gas—but temperature in turn is another interacting factor, and so is the initial mass

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of the gas and its purity" (p. 55).

Although the interactions of the type Phillips describes certainly do occur in the physical sciences, they are nonetheless fundamentally different from ATI effects, because ATI effects are due to individual differences among *people*, differences that are complex, extremely difficult (if not impossible) to measure accurately, and rarely amenable to experimental control and manipulation. In contrast, all molecules of a given gas are essentially identical to each other, and factors such as mass, temperature, and pressure are easily controlled in the laboratory. Even if two samples of gas differ in their purity, it is quite easy to mix the two samples and redivide them into two new samples that are then, for all practical purposes, identical. Indeed, it is this very control of physical factors that makes the discovery of the physical laws of nature possible. In contrast, student variables such as intelligence, motivation, cognitive style, socioeconomic status, and background knowledge are at best extremely difficult to measure and impossible to control.

Phillips also argues that although time itself may be an interacting independent variable in the social sciences, this is also the case in the physical and biological sciences where objects, organisms, and species also change over time. Phillips once again seems to ignore a crucial distinction, however, because in the social sciences the ATI perspective recognizes that the "laws" themselves may change over time, a possibility that is not a concern in the physical sciences. Thus, although no one supposes that the biological process of mitosis (cell division) will change in the coming years as a result of our increasing knowledge of this process and its dissemination, it is easy to imagine how a teacher's use of schedules of reinforcement to maintain discipline in a high school classroom may lose its effectiveness after the establishment of a high school course in psychology in which the principles of operant conditioning are made known to the students.

Although Cronbach and Snow's discussion of ATI problems implies considerable difficulty for educational researchers, it could easily be argued from a less positivistic and more ethnographic and phenomenological perspective that their ATI perspective does not go nearly far enough to appreciate fully the role of individual differences in behavior. This is because Cronbach and Snow imply that the data necessary for a comprehensive theory of human behavior are in principle obtainable using current quantitative ("etic") data collection and analytic techniques, but that time limitations and other practical constraints make it impossible to obtain simultaneously all the data necessary for weaving into a comprehensive theory. However, a more qualitative, ethnographic ("emic") approach to the problem of understanding human behavior would consider that it is not the environment or external stimuli described in "objective," etic terms that influences our behavior but rather it is the *meaning* that each individual attaches to his or her experiences of the environment and that this meaning is influenced by an extremely complex myriad of social and cultural factors. Such a perspective would appear to make predicting human behavior even more problematic than the perspective provided by Cronbach and Snow because the meaning one attaches to one's experiences is a function of the totality of all previous experiences, something to which the researcher cannot possibly have access.

A final perspective on the complexities of individual

human differences is given by Sagan (1977), who estimates that the human brain has some 10^{13} synapses permitting some 2 raised to the power 10^{13} different possible states, "an unimaginably large number, far greater, for example, than the total number of elementary particles (electrons and protons) in the entire universe" and that "it is because of this immense number of functionally different configurations of the human brain that no two humans, even identical twins raised together, can ever be really very much alike." Sagan goes on to speculate that "these enormous numbers may also explain something of the unpredictability of human behavior and those moments when we surprise even ourselves by what we do" (p. 42). A consideration of the interaction of these individual brain differences with educational treatments leads to an appreciation of the enormous difficulty in attempting to predict the effect of an educational treatment on the behavior of any given individual student or group of students, regardless of the findings of previous educational research on the treatment in question. Thus even from what many today would consider a simplistic and outdated positivistic, etic approach to the behavioral sciences, there appear to be serious difficulties in expecting educational research to be able to discover laws of human behavior in educational settings that would permit prediction and control.

Chaos. Developments in the field of physics also have important implications for arguments concerning the predictability of human behavior. The adoption by the behavioral sciences toward the end of the 19th century of the research perspective and methodology used in the physical sciences is usually considered to mark the birth of "scientific" sociological, psychological, and educational research. The emphasis on quantification, objectivity, experimentation, and inferential statistical techniques still found in mainstream behavioral science clearly shows the influence of the research methods of the physical sciences on those of the behavioral sciences.

It is not surprising that the research model originally adopted from the physical sciences by the behavioral sciences was that of then current and quite successful Newtonian physics, in which it was assumed that all relevant variables could be measured objectively and all physical events were determined completely by (and therefore predictable by knowledge of) preceding events. What is surprising, however, is that whereas the physical sciences have now clearly discarded this view of the physical universe as a giant, predetermined clock, this perspective still dominates mainstream "scientific" educational research. In the field of physics, the Newtonian view has given way this century to a much more complex and puzzling view of nature. To borrow Popper's (1979) analogy, the Newtonian view that all seemingly unpredictable phenomena (such as the formation and movements of clouds) are actually in essence as predictable as clocks has been replaced by the opposite view that all physical phenomena (including all phenomena seemingly as predictable as clocks) are in essence as unpredictable as clouds (pp. 206-255). The two major events responsible for this shift in perspective have been the development of the field of quantum mechanics and the discovery of chaos. Although the development of quantum mechanics predates by several decades the discovery of chaos, chaos is discussed first because it provides a deterministic perspective on unpredictability; quantum mechan-

ics is considered later, along with other indeterminate arguments for unpredictability.

The discovery of chaos by the physical sciences is quite recent, and although Lorenz's (1963) landmark paper on chaos appeared more than a quarter of a century ago, it is only within the last several years that physicists have begun paying serious attention to chaotic phenomena. Chaos has since provided startling new insights into the behavior of physical phenomena ranging from dripping faucets to weather systems (Crutchfield, Farmer, Packard, & Shaw, 1986); in the life sciences, chaos has already been applied with some success to problems involving the spread of diseases (Schaffer & Kot, 1985), the rise and fall of animal populations (Schaffer, 1984) and the functioning of the human brain (Skarda & Freeman, 1987; see Gleick, 1987, for a fascinating and readable description of chaos, its history, and current applications). It thus appears only a matter of time before chaos is applied also to problems of human behavior and education.

A process demonstrating chaos is one in which strict deterministic causality holds at each *individual* step in an unfolding process, and yet it is impossible to predict the outcome over any *sequence* of steps in the process. A simple example of chaos is given by the iterative function $y = 3.7x(1 - x)$ in which the initial value substituted for x is between zero and one and the obtained value of y is used to replace x to obtain the next value of y , and so on. Such an equation might be used to model the population dynamics of a temperate zone insect whose generations do not overlap and whose population size for any year determines the population size for the following year.

What is remarkable about this simple equation is that, although all the values it generates iteratively are *determined completely* by the initial value of x , it is nonetheless *impossible to predict* what any i th value of y will be. One must instead let history run its course by actually putting through the equation the original x value and each new generated x value a total of i times to determine the desired i th value of y . In addition, the values generated by the equation fail to form any sort of recognizable pattern and instead generate values that appear completely random. Thus, although this relationship is characterized by a strict and quite simple deterministic law, the outcome is completely unpredictable, *even with the most precise available knowledge of the relevant initial conditions*. Furthermore, the nonlinearity and iterative nature of the chaotic systems described by this equation causes *infinitesimally tiny differences* in the initial value of x to lead ultimately to *large, unpredictable differences* in the equation's output. This sensitive dependence on initial conditions, more popularly known as the "butterfly effect," was first made widely known by MIT meteorologist Edward Lorenz (1963, 1979), whose research demonstrated how the flap of a butterfly's wings in Brazil could set off a tornado in Texas (1979). It was Lorenz's discovery of the chaotic nature of the equations governing the weather that led him to his startling conclusion that accurate, long-range weather forecasting was impossible regardless of the amount and precision of data available and the computing power available to process it (see Gleick, 1987, p. 17).

Chaos is now the subject of much interest among physicists, mathematicians, biologists, astronomers, and economists and the significance of its discovery has been compared to that of evolution, relativity, and quantum me-

chanics. Although apparently still unknown by most (if not all) social and behavioral scientists, chaos has very important implications for the predictability of human behavior and educational research because it holds that even though the relationship between two variables may be both quite simple and completely deterministic, a nonlinear relationship may nevertheless lead to outcomes that are entirely unpredictable.

It is not hard to imagine how chaos might be applicable to educational settings. For example, it seems reasonable to suppose that the amount of mathematics Lionel will learn today is determined at least in part by what he learned yesterday, and what he will learn tomorrow is influenced by what he learns today, and so forth. In addition, the relationship between the amount of mathematics learned on day d and day $d + 1$ may not be linear so that although in general the more Lionel learns on day d the more he learns on day $d + 1$, learning very much on day d could have the effect of *decreasing* the amount learned on day $d + 1$ if, for example, his teacher and classmates can no longer keep up with him or his excellent performance on day d leads him to overestimate his abilities and reduce his attention and effort the following day. Lionel's mathematics achievement (as well as that of his classmates) could then well be characterized as chaotic because although what he learns by the end of grade 4 may be determined completely by what he knew at the beginning of grade 4, his year-end achievement may be nonetheless completely unpredictable.

To make matters even more chaotic, minuscule differences in mathematics knowledge between Lionel and a classmate at the beginning of the school year may lead to quite large, unpredictable differences in achievement between the two students by year end. Thus the concept of chaos assumes particular importance for educational research when viewed from the ATI perspective of individual differences discussed earlier in that it provides a model for understanding how even infinitesimally tiny initial differences in any of a multitude of factors (e.g., teacher attention, teaching materials, motivation, home background, student background knowledge) could in the course of time lead to significant and totally unpredictable differences in outcomes. The butterfly effect of chaotic phenomena constitutes a particularly vexing curse for psychometricians because no matter how reliable and valid a test may be, identical scores on a pretest will inevitably lead to unpredictable differences on a posttest of later achievement.

Arguments From an Indeterministic Perspective

Though the above two arguments for the unpredictability of human behavior are consistent with a completely deterministic universe, there are also arguments for the view that human behavior is by its nature indeterministic and therefore unpredictable. Three of these arguments are now considered.

Learning and development as evolutionary processes. One of the enduring puzzles in our attempt to understand human learning and cognitive development is what Bereiter (1985) has called "the learning paradox." This paradox involves attempting to understand how it is possible for individuals to acquire more complex concepts and abilities based only on the simpler ones already acquired. The logical difficulties of trying to explain how conceptual development can occur at all has led some psychologists and linguists such as

Fodor (1979) and Chomsky (1980) to the radically nativist conclusion that *all* mental concepts must be determined innately.

There is, however, a surprisingly simple nonnativist solution to the learning paradox, a solution at which both Charles Darwin in 1838 and Alfred Russell Wallace 20 years later arrived independently in their attempts to understand the origin of new species of living organisms. The process of biological evolution they described involving superfecundity, random variation, and selection remains to this day the only widely accepted natural explanation for the origin and diversity of life on our planet and provides as well a model for how more complex learning and concepts can emerge out of simpler ones.

Both anthropologist William Bateson (1979) and philosopher Karl Popper (1979) have made strong arguments for an evolutionary view of learning that involves both chance responses (creative hypothesis generation) to novel stimuli and selection (hypothesis testing) to weed out unproductive responses and retain useful ones. Popper (1979) has described "the growth of our knowledge [as] . . . the result of a process closely resembling what Darwin called 'natural selection'; that is, *the natural selection of hypotheses*" constituting "a competitive struggle which eliminates those hypotheses which are unfit" (p. 261).

Monod (1971), winner of a Nobel prize for his work in molecular biology, provides a particularly colorful account of the essential role of chance in biological evolution.

The same source of fortuitous perturbations, of "noise," which in a nonliving (i.e., nonreplicative) system would lead little by little to the disintegration of all structure, is the progenitor of evolution in the biosphere and *accounts for its unrestricted liberty of creation* [italics added], thanks to the replicative structure of DNA: that registry of chance, that tone-deaf conservatory where the noise is preserved along with the music. (pp. 116-117)

Although there is as yet not clear evidence of the actual biological or neurological mechanisms which might underlie evolutionary *cognitive learning*, we do now have quite detailed knowledge of the evolutionary nature of the *biological learning* involved in the mammalian body's immune response, which produces antibodies to fight against harmful foreign substances (antigens) invading the body. Molecular biology has discovered that the immune response is dependent on the *random* generation of antibodies with those found effective in identifying an antigen consequently *selected* for mass production and remembered for the next time the same or similar antigen is encountered (see Ada & Nossal, 1987; Kindt & Capra, 1984; Talmage, 1986; Tonegawa, 1983, 1985; Yancopoulos & Alt, 1986). The now widely accepted clonal-selection theory of the immune system explains the random generation of antibodies as dependent on two different processes: (a) the random *recombination* (i.e., shuffling) of genes for the initial diversity of antibodies, and (b) the consequent random *mutation* of selected antibodies to provide a "fine tuning" to make the antibodies even more effective in identifying a given antigen (Tonegawa, 1985, p. 109). It is remarkable to note that these two random processes are in fact exactly the same processes found in sexually reproducing organisms to provide the random variability in offspring required for biological evolution to take place. Thus we see that the evolutionary process of random

variation (attributable to both sexual genetic recombination and genetic mutation) and natural selection, which over the time span of millions of years resulted in the emergence of the human species, remains as an essential process in the day-to-day survival of the human body in its incessant fight against microscopic foreign invaders. Although the structure and purpose of the immune system may seem at first consideration to be distinctly different from that of the nervous system, physiologists have in fact noted striking similarities between the two (e.g., Cunningham, 1981; Jerne, 1975; Kindt & Capra, 1984, p. 1), and a number of neuroscientists and psychologists have begun to formulate specific models of learning that incorporate the random variation and selection of evolutionary processes (e.g., Changeux & Patte, 1984; Edelman, 1978, 1981; Edelman & Finkel, 1984; Hinton & Sejnowski, 1986; Smolensky, 1986; Waner & Hastings, 1987).

Whereas a conceptualization of learning as an evolutionary process provides a solution to the learning paradox and thus offers an alternative to Chomsky's and Fodor's radically nativist views of human development, its dependence on chance as a generator of hypotheses leads directly to the conclusion that human cognitive development and behavior, insofar as it is based on creative learning, is by its very nature indeterministic and consequently unpredictable. If biological evolution is indeterministic, so then must be creative human learning if in fact such learning is based on similar evolutionary processes.

According to such an evolutionary perspective, even if all the conditions of Earth from its initial formation to the present day could be exactly replicated somewhere else in the universe, it is extremely unlikely that any of the species that have existed on Earth would ever evolve again, because evolution is dependent on random processes. Similarly, an evolutionary perspective on learning suggests that even if a previously found "effective" learning environment could be replicated exactly, it would be very unlikely to lead to the same learning outcomes, *even in an identical physical environment using genetic clones of the original teacher and students*. This realization evidently poses severe difficulties for the generalizability and applicability of the findings of "scientific" educational research.

An evolutionary perspective on education that sees learning and development as processes similar to those of biological evolution and the mammalian immune response suggests that we cannot develop theory that would allow us to predict or deduce the educational outcomes of particular educational experiences. Rather, we can at best develop educational theory that is *compatible* with the educational outcomes observed. This perspective sees educational research as primarily a descriptive science that, even if successful in interpreting and explaining, can never provide a basis for the prediction of an individual's behavior or for the prescription of teaching practices.

Consciousness and free will. An issue of continuing interest in philosophy and psychology has been the existence and role of consciousness and free will in human behavior. Although the peculiarly American behavioristic psychology of John B. Watson and B. F. Skinner denied the existence of both human consciousness and free will, there are today many good arguments for their existence and their central importance in understanding human behavior.

Among these arguments is Popper's (1979) conceptualiza-

tion of human consciousness and its role in regulating behavior. Popper sees human consciousness as a type of higher flexible "plastic" behavioral control (as opposed to a rigid "cast iron" control) that evolved in the course of biological evolution and that interacts with the physical states of the individual. According to Popper, "consciousness . . . is . . . produced by physical states; yet it controls them to a considerable extent" in the same way that "a legal or social system is produced by us, yet controls us, and is in no reasonable sense 'identical' to or 'parallel' with us, but *interacts* with us, so states of consciousness (the 'mind') control the body, and *interact* with it" (p. 251). The essential indeterminate nature of Popper's conception of consciousness is revealed by his description of it as "a system of clouds controlled by clouds" (p. 245).

Attempting to take human consciousness into account to predict behavior raises a number of difficulties. To use an example similar to one given by Popper (1964, p. 13), imagine that it were somehow possible to predict the course of world history over the period of a year and that this "social calendar" were then made widely known. If this occurred, the knowledge of what was predicted would likely influence the accuracy of the predictions. Who would want to fly on Helvetia Airlines flight 31 from Chicago to Geneva on January 13 if it were known in advance that all 267 people on this flight would be lost off the coast of Greenland? What would prevent the price of gold from soaring as investors scurried to buy the yellow metal following the prediction that its price would soon increase dramatically? Making predictions known can influence their accuracy in either of two ways: as in the first example, by warning people so that the prediction is not fulfilled, and as in the second, by making what is essentially a self-fulfilling prophecy. Furthermore, attempting to take account of individuals' reactions to predictions in the predictions would lead to an infinite regress if the new predictions were also made public, for then individuals' behavior would be influenced by the new predictions that took their initial reactions into account, and so on and so forth.

MacKay (1967) uses a related argument to argue for the existence of free will. MacKay asserts that even if the universe is a deterministic clockwork, it nonetheless can be demonstrated logically that humans by their very nature possess a free will that transcends this determinism. To appreciate the main points of MacKay's argument as summarized by Gazzaniga (1985, pp. 142-144), imagine that a brain scientist tells me that after a detailed study of the brain of my wife, he has a complete understanding of its structure and activity and can therefore predict that she will consume a bowl of oatmeal at 7:30 a.m. If we then observe my wife engaging in the predicted behavior at the predicted time, the brain scientist may well boast: "There, I have demonstrated that I can predict your wife's behavior accurately from my knowledge of her brain's structure and processes. She may *believe* that she is acting according to her own free will, but in fact her behavior is completely determined and therefore, in principle, completely predictable."

The trouble with the brain scientist's prediction, however, is that it would not necessarily hold true *if my wife were made aware of the prediction* since she could then easily have eggs for breakfast to prove the prediction wrong. If the brain scientist then tried to take my wife's knowledge of his

prediction into account, he would only be demonstrating that *he could not make a valid prediction of my wife's behavior that was independent of my wife's knowledge of and belief in his prediction*. In other words, the brain scientist

cannot produce a complete specification that will be equally accurate whether or not it is believed by my wife, and so inevitable for her. Since such a prediction cannot be considered 'universally true,' there is a 'logical indeterminacy' about the future states of people's brains; and it is this fact that allows for the concept of free will. (Gazzaniga, 1985, p. 143-144)

From both MacKay's and Popper's perspectives, it would appear that the accurate prediction of complex and creative human behavior must take into account the interacting and regulatory nature of human consciousness. Yet attempting to account for the role of consciousness in behavior poses seemingly insurmountable difficulties for the behavioral scientist because, in addition to the logical problem of indeterminacy discussed by MacKay, an individual's consciousness is not and cannot be made known to the researcher. And yet to attempt to predict complex and creative human behavior of the type that takes place in all educational settings without taking consciousness into account would appear to be as futile as a deaf physicist's attempting to recreate Mozart's symphonies by studying Mozart's body and his environment "as physical systems, and predicting where the pen would put down black marks on lined paper" (Popper, 1979, p. 254).

In summary, there appear to be good reasons for the belief in the existence of both human consciousness and free will and their influence on human behavior. Even if the above arguments are not accepted, however, there is a final line of reasoning that would seem to establish clearly the unpredictability of complex human behavior as regulated by consciousness. As Popper (1964) has observed, human behavior via consciousness is influenced by scientific knowledge, a claim that can be accepted easily by considering the influence of Pasteur's discovery of disease-causing microbes on medical practices or the effect of the manufacture of nuclear weapons on the behavior of world leaders. Yet, as Popper has noted, "we cannot predict, by rational or scientific methods, the future growth of our scientific knowledge. . . . We cannot, therefore, predict the future course of human history" (pp. vi-vii). Adding this argument to others already made should make it clear that there are severe logical difficulties with the view that human behavior is deterministic and predictable.

Quantum mechanics. The development of quantum mechanics during the first half of this century was the first major revolution in scientific thought to lead physics to discard Newton's deterministic, predictable, clockwork universe. Although it is clearly beyond the scope of this essay to provide a detailed discussion of quantum mechanics, an essential characteristic of quantum mechanics that has important implications for the current argument will be considered, that is, the randomness and indeterminacy of subatomic phenomena.

Herbert (1985) gives an easily understood example of quantum randomness that involves shooting individual electrons from an electron gun through a tiny aperture onto a phosphor screen. As each electron strikes the screen, a flash of light indicating the location of the collision appears on

the screen. What is of particular interest in this example is that even if each electron is fired from the gun with exactly the *same* measurable orientation, energy, and velocity, each electron will strike the screen at a *different* location. Increasing the rate at which the electrons are fired will produce what is known as an Airy pattern, a target-shaped configuration whose bright bands indicate regions struck by many electrons and whose darker bands indicate less popular areas of the screen. What is significant in this example is that although the relevant variables describing each electron as it is fired are known and identical, each electron strikes the screen in a different, unpredictable location. There is nonetheless some "striking" order to this randomness because, whereas the exact location that a given electron will land is *unknown*, the probability of striking a given area *is* known and can be reliably replicated by different researchers in different laboratories. As Herbert explains, "the orthodox ontology explains the fact that unmeasured electrons are identical *in being* but different *in behavior* by appealing to quantum randomness. The essence of quantum randomness is simply this: identical physical situations give rise to different outcomes" (p. 118; emphasis in original).

It is worthwhile to pause here briefly to compare the probabilistic nature of quantum physical phenomena with what Gage considers to be the probabilistic nature of educational research findings. Gage (1982) discounts the current pessimism concerning the value of "scientific" educational research as the result of "a failure to accept the value of the probabilistic findings that educational research has yielded" (p. 11). By "probabilistic findings," Gage seems to imply that, as in shooting electrons at a phosphor screen, we may not be able to direct all students to a certain target successfully nor predict which ones will reach it using a given teaching method, but we may nonetheless be assured that a higher proportion of students will be successful using a teaching method shown by research to be more effective than another.

Though there may well be some truth in Gage's contention that we may be more successful in making probabilistic rather than absolute predictions, it is important to realize that there is a distinction between "the probabilistic findings of educational research has yielded" and the probabilistic findings of quantum mechanics. The probabilistic randomness of quantum phenomena forms an integral part of the phenomena themselves and thus may be considered a type of "objective probability" in that the observed probability distributions are readily replicable and no further refinement of the study's design or measuring instruments can eliminate the observed randomness of the phenomenon under study. In contrast, "the probabilistic nature of educational research findings" is due, at least in a large part, to *error*—error having many sources, including insufficient internal validity (e.g., failure to control all relevant variables), deficient external validity (e.g., failure to use a representative random sample), and measurement error (e.g., imperfect unreliability and/or invalidity of the measuring instruments). If the probabilistic findings of educational research as described by Gage were not at least partly the result of such sources of error, they should be replicable in the same way that the Airy pattern is replicable in physics. Because the only way we can discover the objective probability that may underlie behavior in educational contexts is first largely to

eliminate error and because the pragmatic difficulties of eliminating all sources of error are considerable (e.g., those due to individual differences, unrepresentative samples, measurement error, uncontrolled variables and their interactions), it may not be prudent to put much confidence in the currently available "probabilistic findings of educational research," findings whose probabilistic character is due at least in a large part to error but that could possibly also encompass a share of objective probability.

On the other hand, the finding that all physical events are at their finest level unpredictable seems hardly consistent with the great scientific advances of this century that have enabled us to better predict and control our physical environment. The reason for this apparent contradiction is that at the size scale of nuclear power plants, rocket engines, and even the relatively macro level of the tiny integrated circuits etched on computer chips, quantum effects of objective probability are negligible. At the macro level, we are dealing with large agglomerations of particles and atoms whose quantum effects in a sense cancel each other out. For example, in spite of the solid outer appearance of a marble statue, it is actually composed of rapidly and randomly moving clouds of subatomic particles. Although these clouds of particles move randomly, their movements are effectively neutralized, because for every several trillion or so particles moving at a given instant in a given direction, a comparable number move in the opposite direction and so the statue appears immobile. Nonetheless, it is in principle possible that a majority of the particles in the statue's arm could move in the same direction at the same time so that the statue appears to wave, although the probability of such an event is so minuscule that it would rightly be considered a miracle. Therefore, though quantum randomness reigns at the subatomic level, it is not usually observed in the macro world of our everyday existence.

It is, however, of interest to observe that as the components of computers and other sophisticated electronic equipment become ever smaller, the quantum randomness of individual electrons and other subatomic particles (e.g., gamma radiation from outer space) may begin to manifest itself in the functioning of these components. These components will then in a sense amplify these quantum events into events of the macro world that will then be observed as computer programs that fail and electronically guided laser weapons that strike the wrong target. In like manner, it has been proposed that quantum effects could have an influence on human behavior. Popper (1979, pp. 227–228) describes the notion of a "quantum switch" by which unpredictable quantum phenomena in the human body may be amplified to the macro level, where they manifest themselves in our behavioral decisions. Although there is no known evidence for such a quantum switch, so little is known about the inner workings of the human brain that such a mechanism cannot be ruled out. If, as argued above, complex forms of learning are dependent on the randomness of evolutionary variation, there is a certain appeal in speculating that the irreducible, objective probability of quantum phenomena provides the seeds of such variation.

Though presently we can only speculate about the role of quantum randomness in cognitive processes, it is known that quantum phenomena do play an important role in biological evolution. Radiation by subatomic particles results in genetic mutations, which serve as an important source

of natural variation, which is the very fuel of biological evolution. If the tiny and usually imperceptible quantum effects of such radiation are seen as responsible for the great complexity and variety of the biosphere (including the difference noted by Popper between an amoeba and Albert Einstein), then it would seem to be no great conceptual leap to suppose that similar random events could have similar observable influences on the learning and behavior of human beings.

The essential randomness of subatomic phenomena is not the only characteristic of quantum mechanics that has implications for behavioral, social, and educational research. Three particularly intriguing additional aspects of quantum mechanics are (a) that the simple observation (measurement) of a particle changes the particle, (b) that an entity can exist in two apparently contradictory states simultaneously (as in the well-known wave-particle duality of light energy), and (c) Bell's Theorem, which states that all reality is nonlocal, that is, that everything in the universe is connected to and influences everything else in the universe at a speed faster than that of light. Although these additional aspects of quantum mechanics cannot be discussed further here (see Herbert, 1985, for a nontechnical presentation of these and other aspects of quantum physics), it should be clear that the universe of physical phenomena discovered by quantum mechanics has very little in common with the mechanistic, deterministic universe of classical Newtonian physics or "scientific" educational research.

Albert Einstein and Niels Bohr, the two giants of modern physics, never resolved their continuing debate over the fundamental nature of matter and its behavior. In spite of the fact that Einstein's own work was instrumental in the birth of quantum mechanics, his view of the universe remained deterministic, and he was absolutely steadfast in his conviction that the randomness observed in quantum phenomena were due to "hidden variables," which, if discovered and understood, would in principle allow for perfect prediction of all physical phenomena. Einstein's strong belief in a deterministic universe and his aversion to a probabilistic one is well reflected in his often-quoted assertion that God does not play dice. In contrast, Bohr, the leading figure of the Copenhagen School of quantum mechanics, maintained that the uncertainties and probabilities observed in quantum phenomena are intrinsic to the phenomena themselves and not the result of incomplete knowledge. Now, more than half a century after the discovery of quantum phenomena in physics, it appears quite clear that Bohr was right and Einstein was wrong. It would thus appear wise for educational researchers (especially those engaged in the "scientific" pursuit to discover all the "hidden variables" that will allow the prediction and control of educational outcomes) to take a lesson from modern physics and recognize that the behavior of nature's most complex known beings should not be expected to be any less complex or more predictable than that of its most elementary particles.

Implications for Educational Research

Five separate arguments have been made for the unpredictability and indeterminism of human behavior. Because mainstream "scientific" research continues to be based on the conviction that human behavior is in principle determinate and predictable, the validity of even one of these

arguments has important implications for educational research.

First, an acceptance of the unpredictability of human behavior paints a decidedly pessimistic picture for researchers using "scientific" methods of educational research in an attempt to predict and control human behavior in educational contexts. At the same time, the essential unpredictability of human behavior explains why educational research has neither experienced the advances nor enjoyed the consensus that research in the physical sciences has enjoyed. Even Phillips, cited above arguing for certain similarities between educational and physical science research, has stated that "social scientists have not been able to discover generalizations that are reliable enough, and about which there is enough professional consensus, to form the basis for social policy" and that while "the situation may suddenly turn around . . . there seems to be no good reason to expect this to happen" (1980, p. 17). Indeed, the arguments made here provide good reasons why we should not expect such a turnaround.

If "scientific" educational research is thus indeed doomed to failure, the question naturally arises as to what kind of educational research can and should take its place. This is obviously a very difficult question to answer, and space limitations do not permit a complete attempt here. One possible response would involve a change from the orthodox "scientific" research perspective that attempts to predict and control to one that attempts "only" to describe, appreciate, interpret, and explain the social and individual behaviors as well as the cognitive processes relevant to understanding educational phenomena. Educational research from such a perspective would be essentially descriptive, with useful units of study varying from the macro level of community, school, and classroom to the more micro level of individual behaviors, feelings, and cognitive processes.

At the macro level, such research could involve the descriptive and interpretive study of educational contexts of both the present and past in cultures both familiar and foreign involving phenomena both common and exceptional. Detailed descriptive studies of educational policies, practices, behaviors, feelings, and outcomes is of interest and value in that it leads to an appreciation of the complexity of education and suggests what is possible and what may not be. Most important, it provides ideas for innovations, a crucial source of variation for education to continue to grow and evolve creatively. We must, however, always guard against the temptation to make hard and fast predictions of human behavior and devise "cookbook" solutions to problems based on our understanding because, as argued here, it is a serious error to believe that one can predict the future based on what has happened in the past (see also Popper, 1964). Though such research might (indeed, *should*) lead to the implementation and dissemination of innovative educational practices, it must be realized that regardless of the extent of prior research, accurate prediction of outcomes is not possible, and so continuous monitoring and fine-tuning is essential to any educational undertaking.

At the micro level, descriptive studies could be conducted to improve understanding of the social and cognitive development and problem-solving processes of individual students, teachers, administrators, and policy makers. Much recent research in child development evolving out of the Piagetian perspective, which focuses on individual children,

is compatible with this perspective because it provides qualitative descriptions of cognitive functioning and development, which make possible an appreciation of the mental processes and problem-solving strategies used by children in educational settings. This approach contrasts sharply with "scientific" educational and psychological research which, for example, uses unidimensional numbers derived from quantitative measures of intelligence and home background to make linear predictions concerning similar numbers obtained from standardized tests of educational achievement. Again, however, we must guard against the temptation to consider any research as providing knowledge of universals of behavior or psychological development that would enable us to make specific predictions because the complicating factors of individual differences, chaos, the evolutionary nature of learning and development, the role of consciousness and free will in human behavior, and the implications of quantum mechanics all pose grave difficulties for the accuracy of any such predictions. Though such research may provide important information about the possible, it tells little if anything about what is necessary or inevitable.

Returning to the macro level, such a descriptive, non-predictive approach to educational research is quite consistent with the case study approach advocated by Stake (1978), among others, for improving our understanding of education. Stake has written that "one of the more effective means of adding to understanding for all readers will be by approximating through the words and illustrations of our reports, the natural experience acquired in ordinary personal involvement" (p. 5). Stake also contrasts the expansionist nature of the case study method with the reductionist character of orthodox educational research in stating that "theory building is the search for essences, pervasive and determining ingredients, and the makings of laws. The case study, however, proliferates rather than narrows. One is left with more to pay attention to rather than less" (p. 7).

Concerning the micro level of individual cognitive processes, Gruber (1985) feels that "probably the most general reason for studying the case is the need to make models of complex processes. Averaging across subjects blurs our view of exactly that which we want to study" (p. 170). It should not be surprising that Gruber, author of a work of major importance on the life and creative thought of Charles Darwin (1974), believes that behavioral research should attempt to capture and interpret the *complexity of behavior* and suggests that "rather than concentrating so much effort on looking for general laws of human functioning, look for laws of the individual" (1985, p. 172).

This view of educational research is one that takes as its primary goal and responsibility the dissemination of descriptive educational findings to other researchers, teachers, administrators, and policy makers in a form that is meaningful and useful. At the macro level, it provides information about how things could be otherwise by providing vicarious experiences from outside one's limited personal experiences to serve as sources of variation and conjecture to fuel the evolution of educational practice and policy. Such research at the more micro level may provide insights into the perspective of the student as he or she faces the various cognitive and social tasks presented in educational contexts.

Thus the ultimate, achievable goal of educational research may include (a) a realization of the limitations imposed by

the inherent unpredictability of human behavior; (b) the dissemination of this awareness to other educational researchers, teachers, policy makers, administrators, students, and parents; (c) an understanding of learning as an essentially unpredictable, evolutionary process; (d) an appreciation of what has been and thus what may likely still be achievable in educational contexts; and (e) a better understanding of the student's (and perhaps also the teacher's, administrator's, policy maker's, and parent's) perspective on the tasks required of him or her in educational settings.

Although such an approach to educational research has little in common with the obsolete classical, clockwork physics of Newton, it does have much in common with another quite successful field of inquiry into the life sciences, i.e., evolutionary biology. Although it makes no hard and fast predictions about the future viability, morphology, or behavior of its objects of study, evolutionary biology has nevertheless provided a deep understanding of the diversity of life on our planet, the origin of its species, and the dynamics by which living organisms vary, modify their environment, and adapt to it. It should therefore be of at least some comfort to educational researchers to realize that Darwin's original insights resulted from his extensive *descriptive and interpretive* study of organisms, their diversity, and their environments and that the impact of his insights on science was due largely to his extensive *descriptive and interpretive* documentation of his research.

To end on another positive note, it will be observed that although this essay has made arguments for what some may consider to be a quite melancholic view of educational research, the factors underlying the unpredictability and indeterminacy of human behavior are the very same factors that provide humankind with unlimited potential for continued cultural evolution and personal development. Viewed from this perspective, the unpredictability of human behavior and the problems it imposes on "scientific" educational researchers seem a very small price to pay for the inherent freedom and unlimited potential of our species.

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