IS A FINAL THEORY CONCEIVABLE?

DONALD W. ZIMMERMAN
Carleton University

Some physicists believe that a final theory, which will unify separate branches of theoretical physics, including quantum field theory and general relativity, is imminent. The physicists who expect such a theory typically assume that ultimate natural laws will be expressed by the same mathematical formalism which is associated with present-day physics. This view is questionable, because mathematics itself evolves and is not currently in a finished form. Historically, a succession of discoveries in physics has unveiled new laws of nature, each stage being made possible by the development of new mathematics. Evolutionary biology and interbehavioral psychology, ordinarily overlooked by the philosophy of science, reveal further inconsistencies inherent in the concept of a terminal stage of scientific discovery. Another troublesome implication of this notion has come to light recently: finality of a conceptual scheme comprised of a finite number of natural laws is incompatible with recent developments in mathematical logic and the theory of computational irreducibility.

Throughout scientific history, the hope of a final theory has endured in various forms and recently has appeared in the writings of several physicists. For example, Weinberg (1993) expressed the idea as follows:

The dream of a final theory inspires much of today's work in high-energy physics, and though we do not know what the final laws might be or how many years will pass before they are discovered, already in today's theories we think we are beginning to catch glimpses of the outlines of a final theory. (p. ix)

Weinberg also wrote:

Our present theories are of only limited validity, still tentative and incomplete. But behind them now and then we catch glimpses of a final theory, one that would be of unlimited validity and entirely satisfying in its completeness and consistency. (p. 6)

Send correspondence to Donald W. Zimmerman, 15078 Eagle Place, Surrey, B.C. V3R 4W2, Canada. Phone: (604) 930-8297, Fax: (604) 930-8298, E-mail: zimmerma@direct.ca.
Hawking (1993, pp. 49-68) put forward a similar point of view and referred to "a complete, consistent, and unified theory of the physical interactions that would describe all possible observations." This notion of a "grand unified theory" or a "theory of everything" has become prominent in elementary particle physics in recent years. See also Davies and Brown (1988) and Glashow and Bova (1988).

At first glance, the conception of a grand scheme that describes all possible observations has considerable appeal. Authors who admit this possibility usually assume that such a scheme will be formulated in the language of contemporary mathematics and physics and that it will consist of a small finite set of natural laws. For the most part, authors do not speculate about the subsequent role of physics and the relation of sciences to other areas of human culture, after the coming of the final theory. Occasionally, they suggest that science will not necessarily end, but will never produce more "fundamental" theories. Some authors apparently believe that a completed theory is not too far away.

Whenever this idea is expressed, one recalls the status of physics at the close of the nineteenth century. Many physicists at that time believed that the subject was completed once and for all except for a few small clouds on the horizon. A short time later, relativity and quantum mechanics overturned this conviction in a rather spectacular way. Nevertheless, the premise that a finished theory will appear in the not too distant future still survives despite past disappointments.

Evolution of the Concept of a Final Theory

The notion of a final theory has taken on different guises as science itself has evolved. Speculative philosophers, including Plato and Aristotle in antiquity and many medieval thinkers, entertained hopes of a grand synthesis before the rise of modern science. Later, Descartes, Spinoza, Leibnitz, Locke, Berkeley, Hume, Kant, and Hegel constructed systems which were influenced in varying degrees by the new science. Many other philosophers in the eighteenth and nineteenth centuries took seriously the possibility of a "theory of everything," which usually was intertwined with a transcendental metaphysics. More recently, Whitehead (1928/1978) expressed a philosophical view, greatly influenced by nineteenth and twentieth century science, but still rooted in past metaphysics, in this way:

Speculative philosophy is the endeavor to frame a coherent, logical, necessary system of general ideas in terms of which every element of our experience can be interpreted. By this notion of "interpretation" I mean that everything of which we are conscious, as enjoyed, perceived, willed, or thought, shall have the character of a particular instance of the general scheme. Thus the philosophical scheme should be coherent, logical, and, in respect to its interpretation, applicable and adequate. Here "applicable" means that some items of experience are thus
interpretable, and "adequate" means that there are no items incapable of such interpretation. "Coherence," as here employed, means that the fundamental ideas, in terms of which the scheme is developed, presuppose each other so that in isolation they are meaningless. (p. 3)

Comparison of this passage and the ones written by Weinberg reveals similarities. It is interesting, however, that Weinberg, the physicist, is somewhat more optimistic about attaining a final theory than is Whitehead, the philosopher, who stated subsequently that "Philosophers can never hope finally to formulate these metaphysical first principles."

Present day physicists, including Weinberg, Hawking, Glashow, and others, focus attention on a scientific theory of everything, which is viewed in a more restricted framework than the speculative philosophy of the past. Since the time of Galileo and Newton and the rise of mathematical physics, scientists seek general laws of nature expressed in mathematical form, instead of metaphysics. Today, many physicists assume that these ultimate laws will constitute some refinement of quantum field theory.

In another sense, however, the current conception is more general than the diverse speculations throughout the history of philosophy. In the past few centuries, science has encountered new phenomena, previously not anticipated by the most venturesome and creative thinkers of the past. To explain these new phenomena, science has devised increasingly more elaborate theories based on mathematical constructs not formerly available.

As a simple example, the manner in which Spinoza or Hume dealt with the problem of cause and effect in nature is quite different from current ideas, as a consequence of the findings of quantum mechanics in the early twentieth century. That theory placed the centuries-old problem of determinism in a new context that was not anticipated by any of the great speculative philosophers. And as a result, our ideas about cause and effect and related topics today are broader in scope and conceptually richer than the arguments of the philosophical systems of the past. At the same time, these developments in quantum theory brought into existence new and unforeseen philosophical problems—for example, non-locality in physical interactions.

In the time of Newton and Hamilton, the dream of a final synthesis could be expressed by the question: Is it possible to discover general laws of motion, formulated in the language of differential and integral calculus, which can explain all physical processes? Today, as a result of several intervening centuries of discovery, it is more appropriate to ask: Is it possible to formulate a unified field theory which includes both quantum mechanics and relativity? The difference in the form of the question, as well as the very concept of a final theory, or philosophical synthesis, reflects the vast changes in both science and philosophy in a few hundred years.
Is a Final Mathematics Conceivable?

Transferring the question to another domain, mathematics, yields insight into the problem. The philosophy of science in the nineteenth and twentieth centuries was grounded largely in developments in mathematics and physics. Certainly, mathematics always has been an important constituent of laws of nature. Frequently, the formal symbolic constructs and relations underlying a physical law have been taken as "given," and the fact that mathematics itself has undergone extensive transformation throughout history and still is changing has been overlooked.

Along with the question "Is a final theory conceivable?" which usually is understood to refer to a physical theory, it is also obligatory to ask "Is a final mathematics conceivable?" Frequently, the abstractness of mathematical concepts appears to transcend applications. Nevertheless, a closer look reveals that new mathematical results, purely formal at first glance, have been to a large extent motivated by physical applications (see, for example, Boyer & Merzbach, 1991; Kramer, 1970).

Conversely, progress in physics and other sciences frequently depends on mathematical advances. Newton's mechanics was made possible by the discovery of differential calculus. Maxwell's electrodynamics depended essentially on vector analysis. The formalism of modern quantum mechanics includes theorems in functional analysis, the geometry of Hilbert space, and group theory. General relativity requires tensor analysis. Thermodynamics and statistical mechanics depend on the theory of probability and stochastic processes. Thus, interdependence of physical theory and mathematical formalism has prevailed throughout recent history. With each major theoretical advance, there has been associated a corresponding mathematical structure, unavailable to physicists of the past, without which the new theory could not have been formulated.

It is natural to ask, therefore, if a final physical theory will be supported by a final mathematics. This question lays bare some of the dilemmas inherent in the notion of a final theory. It is especially difficult to imagine the existence of a final mathematics beyond which no further development occurs. Modern ideas about computational irreducibility, originated by Turing (1936) and others, reinforce this outlook. These ideas will be discussed in more detail later in this paper. Today, there are many unsolved problems at the frontiers of mathematics, and the need for unification of specialized areas is just as compelling as it is in physics.

Category theory (see, for example, Arbib & Manes, 1975; Blyth, 1986; Pierce, 1991) is a prime example of a system which unifies and enhances understanding of a multitude of specialized axiomatic systems. But even the sweeping generality of this theory does not represent a conclusion of the development of mathematics. On the contrary, it is compatible with the existence of an infinite number of
structures, still to be originated, describable by categories and functors. And problems of the foundations of mathematics are still open and in many ways as perplexing as they were at the end of the last century.

The further question arises as to how many still-to-be-conceived abstract structures have, or will have in time, physically meaningful applications. It is possible that there is no end to the elaboration of mathematical categories and, at the same time no end to physical interpretations of subclasses of those categories. Certainly, in the past, new mathematics has been followed by scientific applications. Abstract systems which are inherently appealing in an esthetic sense and at the same time closely interrelated with already established axiomatic systems frequently turn out to have major applications that at first were unsuspected. Group theory, vector analysis, Hilbert spaces, and measure theory are just a few examples.

These observations are inconsistent with the supposition that at some point in the future a system of physical laws will be complete, based on an ultimate mathematical system. As long as physics and mathematics were thought to be separate and distinct fields, these difficulties were not apparent. However, recognition that the two are interrelated and evolve together makes the notion of a final physics based on a final mathematics doubtful. A more probable outcome, consistent with the historical record, is that of an unending process of discovery, both in physics and mathematics, with the continual appearance of new domains of phenomena which require unification.

A final theory as envisioned by physicists—one that encompasses both quantum theory and relativity—is especially implausible because these two theories are based on incompatible mathematical models. This fact was pointed out by Bohm (1980):

Relativity theory requires continuity, strict causality (or determinism) and locality. On the other hand, quantum theory requires non-continuity, non-causality, and non-locality. So the basic concepts of relativity and quantum theory directly contradict each other. It is therefore hardly surprising that these two theories have never been unified in a consistent way. Rather, it seems most likely that such a unification is not actually possible. What is very probably needed instead is a qualitatively new theory, from which both relativity and quantum theory are to be derived as abstractions, approximations, and limiting cases. (p. 176)

If this view turns out to be correct, a synthesis of quantum theory and relativity will occur within the context of more general natural laws which extend beyond both of these theories. This broader perspective in turn will push the frontiers of science still further ahead and disclose more unsolved problems. There is no reason to believe that this state of affairs will ever come to an end, even in the remote future.
If Newton, Hamilton, and Maxwell were transported into the present, they would not have difficulty in comprehending the general nature of the unified theory which physicists now seek, although they probably would be astonished at how their own contributions have been enlarged and transformed. These theorists in their own time sought a grand scheme which would encompass all things. Although their accomplishments were restricted from our present viewpoint, they could understand and appreciate the modern quest for finality.

Changes in physics, however, have been accompanied by parallel developments in other sciences that most likely would cause these earlier physicists considerable bewilderment. These innovations appeared in chemistry, geology, biology, and astronomy, which have been somewhat neglected by philosophers of science in their enthusiasm for mathematics and physics. As a result of advances in these fields, it is no longer feasible to regard the history of physics as a progression toward a final synthesis.

Most notably, Darwin's findings in evolutionary biology suddenly injected historical inquiries, as well as predictions about what is to come in the future, into a novel conceptual framework. Newton and his contemporaries recognized that superficial features of the surrounding world could change throughout a limited duration, but they regarded many human characteristics, including rationality and other mental capacities, as invariant. This outlook changed radically after Darwin. It was not an enormous leap from biological evolution to the generalization that galaxies, living species, and scientific theories all are examples of preexisting materials continually generating novel forms in a continuous process that never ends.

Psychologists who discerned connections between evolution and psychology at first retained a dualistic point of view. They proposed to study the evolution of psychological capacities and abilities, identifying these with species-specific traits studied by Darwin. Although not generally recognized by philosophers of science, or even by psychologists, Kantor (1924,1933,1938) was one of the first of a relatively small group of theorists who understood the implications of evolutionary biology for psychology. Kantor realized that the interaction of an organism and its environment itself exemplifies an evolutionary process. More recent proponents of a similar point of view include Campbell (1960), who introduced the expression "evolutionary epistemology;" Hull (1974); Mayr (1988); and Popper (1959). As Kantor (1938) observed:

To inquire also into the origin and passing away of phenomena is to enter into a dynamic phase of science and to be concerned with events. Since science attained this last stage of development the necessity to investigate the history of the phenomena dealt with has become an important criterion for their differentiation ... In biology it is a foregone conclusion that the study of the
evolution and development is indispensable for the understanding of organisms and their behavior. But even in biology, evolution is merely necessary to understand the fine balance between function and structure. When we come to psychology where there is no substantive structure, developmental facts constitute the very essence of the phenomena. Such phenomena must be studied as durational and continuative, since the activity on the part of both the interbehaving organism and object originates in their past contacts. (p. 42)

And Kantor (1969) also wrote:

In addition to being a salubrious influence for making psychology into a natural science, it happens that evolution is itself the very essence of psychology. Not only is psychology the study of field situations, but all those situations are evolutional or historical. The interrelation of the organism with its stimulus objects is in every instance a function of previous interrelations. Thus, an essential characteristic of psychological events is their evolution during particular intervals of time and the same is true of biological evolution. Both types of evolution consist of immense and successive colligations of factors. (pp. 308-309)

According to this analysis, concepts of evolution and natural selection not only are central to the study of species of organisms over geological epochs, but also are relevant to changes that occur in individual organisms over relatively short periods of time.

In the next stage of this conceptual development, scientific discovery itself was placed in an evolutionary context. In 1938 (p. 45), Kantor remarked that “science in all its phases constitutes controlled interbehavior with concrete phenomena” and later elaborated extensively on this point of view. Popper (1959, p. 108), who maintained that knowledge advances through falsification, rather than verification of earlier theories and inspired a reevaluation of logical positivism, also adopted a biological point of view: “We choose the theory which best holds its own in competition with other theories; the one which, by natural selection, proves itself the fittest to survive.”

The fact that natural selection can explain the most remarkable and specialized curiosities of human experience had not been anticipated by science or by philosophy. Twentieth century biologists, including Haldane (1932) and Oparin (1938/1968), argued convincingly that the origin of life on the earth was neither accidental nor planned, but, rather, inevitable. Ashby (1960) emphasized the same thing and observed that natural selection over an extended period generates, as a matter of course, complex structures which exhibit highly coordinated behavior:

The development of life on earth must thus not be seen as something remarkable. On the contrary, it was inevitable. It was inevitable in the sense that if a system as large as the surface of
the earth, basically polystable, is kept gently simmering dynamically for five thousand million years, then nothing short of a miracle could keep the system away from those states in which the variables are aggregated into intensely self-preserving forms. The amount of selection performed by this system, of which we know only one example, is of an order of size so vastly greater than anything we experience as individuals, that we not unnaturally have some difficulty in grasping that the process is really the same as that seen so trivially in our everyday systems. Nevertheless, it is so; the greater extension in space enables a vastly greater number of forms to be tested, and the greater extension in time enables the forms to be worked up to a vastly greater degree of intricate co-ordination. (p. 233)

Essentially the same argument is relevant to the origin of complex structures in the interbehavior of an individual organism and its surroundings. For the word “life” in the first sentence, one can substitute words such as “language,” “society,” “cognitive processes,” “thinking,” “art,” and so on, and, with a few minor changes, the passage still is meaningful. All kinds of phenomena which at first glance appear highly improbable become less mysterious if incorporated into an evolutionary context. This is true of atoms, molecules, cells, brains, and societies.

These ideas, which originated outside of physics, diminish the likelihood of a final theory. If one looks at the scientific enterprise in its entirety, it becomes evident that all fields are interrelated and that a terminal physical theory is incompatible with discoveries in sciences outside the boundaries of physics. The findings of evolutionary biology, interbehavioral psychology, and modern mathematics, all taken together, lead inescapably to the conclusion that a final theory in any domain of science is inconceivable.

The Novel Perspective of Interbehavioral Psychology

Interbehavioral psychologists (Kantor, 1924, 1933, 1938, 1953, 1969, 1981; Kantor & Smith, 1975; Pronko, 1980; Smith, 1973; and others) emphasized that concepts are useful only if they are unfettered by transcendental, autistic, and dualistic constructions. Legitimate scientific theories are based on contacts of scientists and objective events. This position was prominent in many books and articles written by Kantor and others, beginning as early as 1924 and extending over a period of many decades, and it anticipated later developments in psychological theory. Furthermore, it embodied many of the attractive features of positivism, empiricism, and related philosophical movements which were in vogue early in this century, while avoiding their indefensible pronouncements.

Present day philosophers of science, as well as psychologists, have failed to understand at least four distinctive characteristics of the interbehavioral point of view. First, they have not discriminated the novel
aspects of interbehavioral psychology from other forms of behaviorism that dominated the psychological scene in America and elsewhere for many years. They have not recognized that interbehavioral psychology conceptualized and investigated in a strictly scientific manner the "higher mental processes," including thinking, imagining, attention, cognition, and so on, that were neglected by classical behaviorism.

Modern textbooks in cognitive psychology (for example, Benjafield, 1992; Medin & Ross, 1992) typically contain an introductory section explaining how cognitive psychology overcomes limitations of classical behaviorism. Not widely recognized is the fact that these sections to a large extent recapitulate criticisms put forward by Kantor in 1924, 1933, and 1938, as well as many other publications. They also duplicate quite closely criticisms made by Pronko (1980) and other interbehavioral psychologists in more recent times.

Furthermore, philosophers of science have failed to notice philosophical implications of the interbehavioral viewpoint which are distinct from implications of other forms of behaviorism and other types of psychological theory. These illuminate various issues that have been prominent in the twentieth century (see also Kantor, 1981). For example, philosophers' arguments about artificial intelligence (Searle, 1995) would be less persuasive if "interbehaviorism" were substituted for "behaviorism" in these disputes.

Finally, critics focused attention on Kantor's objections to the view that the brain causes behavior, believing that he failed to appreciate the achievements of neuroscience. As a consequence of this misconception, they have not grasped his fundamentally biological and evolutionary point of view, which certainly admits the importance of the nervous system. Even though he objected to "brain-dogma," Kantor's writings as early as 1924 were replete with cogent observations about relations between neurophysiology and psychology. For further discussion of this issue and its implications for neuroscience, see Delprato (1979).

As noted earlier, the interbehavioral theory shares with twentieth-century biology recognition of the interdependence of organism and environment, but it progressed further in incorporating evolution and behavior into its conceptual framework in an original way and describing many subtleties of concrete psychological interactions. One can discern a similar shift in perspective in other sciences. Discussions of quantum theory by physicists who are beginning to challenge the orthodox Copenhagen interpretation appear increasingly more remindful of the premises of interbehavioral psychology. For example, Bohm (1980) observed that

the entire universe has to be thought of as an unbroken whole. In this whole, each element that we can abstract in thought shows basic properties (wave or particle, etc.) that depend on its overall environment, in a way that is much more reminiscent of how organs constituting living beings are related, than it is of how parts of a machine interact. (p. 175)
And Frank (1955, p. 464), along with many other physicists, has emphasized that "speaking exactly, a particle by itself without the description of the whole experimental setup is not a physical reality." These views are more suggestive of Whitehead than they are of Mach. They are more like interbehavioral psychology than versions of psychological theory grounded in classical empiricism and positivism.

The contention that science consists of human contact with objective events, which has been emphasized repeatedly by interbehavioral psychologists, presupposes that scientific theory always is associated with a particular stage of organic evolution, as well as cultural evolution. Considered in this biological context, a final theory implies that there will be an abrupt cutoff in the evolution of organisms and culture on the earth. This state of affairs seems more mysterious than the vexing problems of physics a final theory is supposed to solve. Far more likely is a future of changing science, changing societies, changing language and cognitive structures, and changing brains. And these transformations undoubtedly will be associated with newer and more highly developed scientific theories ensuing from extended human contact with objective events. It is impossible to predict what will come to be in the distant future of the planet. But a reasonable argument from analogy is that it will differ from what exists now as much as the present differs from the remote past.

Scientific Constraint of Philosophical Innovation

Whitehead (1928/1978) reasoned that scientists and philosophers who reject metaphysics are inadvertently influenced by some chance metaphysics which accounts for their beliefs. Currently, an alternative to this famous argument is more plausible: Science delimits the possible scope of philosophical investigations. The two are interrelated, and feedback occurs in both directions, but the dominant causal relationship is from science to philosophy. The ideas of any thinker during a particular historical period are constrained by the science of that period. Moreover, the extent to which a philosopher is familiar with one or another of the various sciences in recent history has been a major determinant of the direction taken by that philosopher's speculations. This dependence of philosophical ideas on science is apparent again and again throughout the history of modern philosophy. Many examples have been given by Kantor (1981).

Therefore, contemporary science determines the direction and scope of possible speculations. As Sober (1994) pointed out:

Philosophers have tried to learn from science in two quite different ways. First, the contents of particular scientific theories have thrown light on philosophical problems. For example, philosophers interested in the nature of space and time have found much of interest in relativity theory. As sometimes happens in the history of thought, a problem that begins its life as a
problem in philosophy later turns out to receive illumination from a body of scientific results. Philosophy then has to catch up with the news from outside . . . Even if philosophy is a discipline that is driven by its own evolving set of problems, this does not mean that scientific ideas are irrelevant to the solution of philosophical problems. What has happened in the past is doubtless happening right now. Science encroaches little by little on what philosophy views as its own terrain. (pp. 1-3)

Another conspicuous example was mentioned earlier. The findings of quantum mechanics have constrained what it is possible to say about the age-old problem of causality and determinism. For further discussion of this issue see Stephenson (1982) and Zimmerman (1979).

Campbell (1960) pointed out that natural selection explains how new ideas which "break out" of an existing framework of concepts occasionally survive and become established. In recent centuries, science has placed rather narrow limits on possible philosophical innovations, and one will survive only if it is consistent with a vast background of scientific information. Furthermore, a great deal of evidence now warrants a stronger conclusion. The cognitive processes associated with philosophical speculation on the part of human beings do not lie outside the domain of science, but, rather, are themselves subject to analysis and explanation by scientific theories. This means that science not only limits the scope of philosophy, it also explains the existence and the direction taken by philosophy.

Undoubtedly, modern biology, psychology, and neuroscience invalidate some of the classical arguments of Locke and Hume. Furthermore, recent findings in these fields are incompatible with later versions of empiricism, including those of Mach, James, and Russell. In speculating about the dependence of knowledge on sensory impressions, philosophers have been influenced by common sense ideas about phenomena such as vision, attention, and short-term memory. The analysis of these phenomena has progressed rapidly in the last few decades.

The modern outlook certainly is antirationalistic, because it denies the possibility of inquiry based on first principles which is exempt from explanation by other forms of inquiry. In contrast, it is opposed to classical empiricism, because it denies that the "experience" of human beings has a privileged role. Carnap's (1928) "logical structure of the world" superimposed an advanced logic on a primitive psychology. As early as 1938, Kantor explicitly discussed in detail and rejected this Machian interpretation of experience decades before Carnap in later work (1956); Feyerabend (1963); Hanson (1967); Hesse (1970); Quine (1953); and others advanced similar arguments. See also Kantor (1969).

Today's physicists who prepare for the coming of a final theory are, for the most part, empiricists. Nevertheless, their thinking brings to mind a doctrine of rationalists of an earlier era—that inquiry is governed by truths which are "given," prior to the ongoing process of discovery.
Rationalists were convinced that purely mental activities which do not include observation and experimentation can yield indisputable knowledge. A similar belief underlies the conviction of early empiricists that sense data provide the beginnings of all inquiry. Contrary to this position, Quine (1953) insisted that "there is no first philosophy." Some of today's physicists, although assuming that a final theory will be attained by the scientific method, nevertheless insinuate that the outcome is inevitable. The belief in the existence of final science, waiting to be discovered, is similar to the belief in a "first philosophy." See also Gregory (1988).

Whitehead (1955, p. 29) remarked that "the red glow of the sunset should be as much a part of nature as are the molecules and electric waves by which men of science would explain the phenomena," and classical behaviorists and many modern advocates of artificial intelligence probably agree that the datum to be explained is not the red glow of the sunset, but rather someone's statement "I see the red glow of the sunset." But interbehavioral psychology extended the analysis further, more in conformity with Whitehead's subsequent statement (1955, p. 29) that "it is for natural philosophy to analyze how these various elements of nature are connected." Interbehavioral psychologists, although recognizing a problem that other behaviorists ignored, would disagree about the status of these "elements of nature," and scientific developments have borne out their position.

Unquestionably, advances of science continually require modification of philosophical views. In Sober's words, "catching up with the news from outside" is a perennial problem. In modern history, developments in the physical sciences repeatedly demolished what first appeared to be self-consistent metaphysical systems. Science now has entered a period where data from biology and psychology are beginning to confine further the content of philosophical speculations, perhaps even more drastically.

Finality and Computational Irreducibility

The idea of a final theory is subject to some further constraints related to formal logic and mathematics that are not obvious. Psychologists are aware that models of information processing provided by computer science have greatly influenced psychological theory in the past several decades. Of course, interbehavioral psychologists realize that "Psychological phenomena are postulated to be original events and not secondary results of other events" and that "The psychologist's borrowing of scientific materials has brought about an unsatisfactory relation to his own" (Kantor, 1938, pp. 15-16). These warnings should be heeded before overextending computer analogies. Moreover, recent findings have raised the possibility that current computer analogies in psychology are rather weak and that the most profound implications of a computational paradigm are yet to come.

Wolfram (1994) and others called attention to undecidable questions
in mathematical models of physical systems, which are a consequence of Gödel's (1931) theorem on undecidability in axiomatic systems and related logical arguments, such as those of Church (1936) and Turing (1936). The basic idea is that theoretical models can be regarded as algorithms, consisting of a finite number of elements, which cannot exhaustively describe real processes. The notion that no finite number of laws of nature can explain all processes in nature is similar to the more familiar theorem that no finite set of propositions incorporates the whole of mathematics.

According to this approach, therefore, there are inherent limitations on the scope of physical theories. These are not externally imposed, but arise within the framework of science itself. Ultimate laws of nature which include everything are just as inconceivable as an axiomatic system which generates all true propositions of mathematics. Certainly, theorems concerning computational irreducibility, incompleteness of mathematical systems, and related ideas in computer science cast doubt on the assumption that an evolutionary product of nature itself is capable of producing a final system of laws encompassing all of nature.

Wolfram (1994) also suggested that some well-defined physical problems characterized by extreme complexity can be answered only by simulation—that is, by observing the actual evolution of a process step-by-step, instead of derivation of the outcome from a general law. He expressed this idea as follows:

In biological systems computational irreducibility may be even more widespread: It may turn out that the form of a biological organism can be determined from its genetic code essentially only by following each step in its development . . . One of the consequences of computational irreducibility is that there are questions that can be asked about the ultimate behavior of a system but that cannot be answered in full generality by any finite mathematical or computational process. Such questions must therefore be considered undecidable . . . Computational irreducibility implies many fundamental limitations on the scope of theories for physical systems. (pp. 447-448)

If this hypothesis is confirmed, it means that some complex physical and biological systems must be studied by methods unlike the derivation of facts from general principles characteristic of mathematical physics.

One naturally considers the possibility that some psychological phenomena are sufficiently complex that their interbehavioral history is computationally irreducible. This certainly does not imply that psychological phenomena are outside the scope of science. On the contrary, these conclusions themselves, whether relevant to physics, biology, or psychology, represent significant achievements of science not envisioned by the investigators of previous centuries. Therefore, the mathematical theory of computation may eventually reveal that systems of laws of nature are essentially incomplete, reminiscent of Gödel's
theorem, and that a final theory is out of the question on purely logical grounds.

Conclusions

It is likely that our present ideas about laws of nature will turn out to be limited in other ways which are unknown. As science evolves, the conception of a scientific theory, final or otherwise, continually changes. The hope of a grand unified theory, which is prominent in theoretical physics today, may be replaced by something quite different in the future. The same provisional status characterizes the most comprehensive theories in all fields.

The limitations discussed in this paper do not oblige science to transfer its unsolved problems to other areas of culture, to nonscientific ways of problem solving, or to mysticism. Rather, these limitations are consequences of a conceptual scheme which, taken as a whole, implies that the potentialities of science are inexhaustible and that there is no end to science. In contrast, an impending final theory which solves all the problems at the frontiers of physics is irreconcilable with the interdependence of physics, mathematics, and biological sciences. Moreover, it is inconsistent with a truism long understood and appreciated by interbehavioral psychologists: The behavior of knowers and discoverers itself is interconnected with the objective phenomena investigated by all sciences.

References

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