THE SCIENCE OF CYBERNETICS AND THE CYBERNETICS OF SCIENCE

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ABSTRACT

Recent developments in cybernetics have challenged key tenets in the philosophy of science. The philosophy of science constitutes a theory of knowledge which is often called realism. However, the philosophy of science is not a unified field, there are a variety of points of view. Contemporary cybernetics, meanwhile, is developing a philosophy called constructivism. This paper compares cybernetics with two important schools of thought within the philosophy of science, lists several different assumptions which lead to misunderstandings between scientists and cyberneticians, and then suggests a way of resolving the differences, not by rejecting science but by enlarging it.

INTRODUCTION

At George Washington University in the United States my colleagues and I have been conducting a debate in recent years on the subject, Is management science a science? For each event the title is somewhat different, but the discussion always concerns whether the contemporary philosophy of science adequately describes the kind of knowledge we feel is appropriate for dealing with social systems. As I understand it, this conference is intended to address similar issues. I believe that these discussions are important because they go to the heart of what we are saying to our students and ourselves about knowledge, science, and the conduct of inquiry.

I have a second reason for encouraging and taking part in this debate at my home university. It gives me an opportunity to define cybernetics for my colleagues and for students who are not in the systems theory and cybernetics program. One professor at my university uses the terms systems theory, cybernetics, and logical positivism interchangeably, a situation which confuses many students. Most other faculty members simply admit that they do not know what cybernetics is, though they assume that it has something to do with computers. My position is that cybernetics has something important to contribute to the prevailing view of science.

We are living in an interesting time -- when major changes are occurring in the philosophy of science. For several decades dissatisfaction with the classical philosophy of science, often called logical positivism, has been increasing. A resolution has begun to emerge only recently. But before we look at the new point of view, I believe it is important to review the contributions of the previous point of view.

THE ACHIEVEMENTS OF THE PHILOSOPHY OF SCIENCE

Within the history and philosophy of science there are many points of view and schools of thought. A detailed explication of the positions of various authors is beyond the scope of this paper (Suppe, 1974). I shall simply describe the two positions which seem to me to be the dominant ones in the philosophy of science at the present time in order to contrast with these two positions the philosophical position of contemporary cybernetics. In order to describe the two positions within the philosophy of science, I shall emphasize the work of Karl Popper and Thomas S. Kuhn.

The philosophy of science constitutes a theory of the nature and progress of knowledge. We should not discard this work lightly. Furthermore, a criticism of any point of view will be most persuasive if it is accompanied by an alternative. It is difficult to persuade people to give up something that has served them well, until there is something better to put in its place. One achievement of the philosophy of science has been to address the problem of demarcation -- how can we distinguish science from non-science? (Miller, 1985) Popper proposed the criterion of falsifiability. Scientific statements can be falsified, non-scientific statements cannot be. This idea, and the previous idea of verification through resort to experiment, has had a beneficent effect on social systems. Through the idea of experimentation, science became a means of establishing knowledge other than by coercion or arguments based on appeals to authority, faith, or supernaturalism. This idea liberated the scientific community from ecclesiastical and state control and reinforced the growth of democratic societies.

Science provided a way for people who were willing to think critically to go beyond doctrine and shared opinion. The idea of trial and error, of conjectures and refutations, has had a liberating effect on human society and has made possible the material progress of recent centuries. Science gave us a way of knowing what we know and what we do not know.

The greatest dispute regarding science in recent decades was generated by Thomas Kuhn's 1962 book, The Structure of Scientific Revolutions. Whereas the positivists defined epistemology normatively -- how scientists should operate -- Kuhn defined epistemology sociologically -- how scientists behave as a social system. Kuhn noticed a discrepancy between how scientific progress was described in text books and how it appeared when reading the original scientific works. In text books the growth of science is usually depicted as having occurred in an orderly, step-by-step manner with each new idea building on previous ideas. However, in the original works there is much debate and conflict. Kuhn suggested that science proceeds through a series of revolutions with periods of "normal science" in between. Normal science he defined as an activity of puzzle solving when scientists are using a widely accepted "paradigm." Kuhn defined a paradigm as being more than a theory but less than a world view.

Kuhn's work was important because it focused attention on the role of communities of like-minded scientists. Kuhn asserted that progress in theories is not merely a matter of accumulating findings but rather that succeeding theories are in fact incommensurable. For example, mass, length, and time are fixed in Newton's theory of mechanics but they are not fixed in Einstein's theory of relativity. Kuhn suggested that the shift from one theory to another bears a resemblance to the process of religious conversion. Whereas positivists contend that theories can be tested through experimentation, Kuhn argued that even data and experiments are subject to interpretation. Kuhn's theory has never held much appeal for philosophers of science, but it has been popular among social scientists. Kuhn's description of science as a social activity is quite similar to other descriptions of social processes including politics and religion. In each case different points of view are developed and advocated by different coalitions which then compete for influence or power.

THE CYBERNETICS CRITIQUE OF SCIENCE

Cybernetians in recent decades have proposed a biological rather than a normative or sociological view of epistemology. They took the classical philosophy of science seriously and used it to study the nervous system. After doing so, they came to the conclusion that it was necessary to reject one of the key tenets of the philosophy of science -- the idea that observations are independent of the characteristics of the observer (Von Foerster, 1981).

Cybernetians now focus on the observer in addition to what is observed (Segal, 1986). They are developing a philosophy of constructivism as an alternative to realism (Von Glasersfeld, 1987). Rather than the idea that scientific laws are discovered, as one might discover an island in the ocean, cyberneticians claim that scientific laws are invented to explain regularities in our experiences. Rather than believing that science describes reality, cyberneticians assert that each individual constructs a personal "reality" which fits his or her experiences. One of the motivations for developing this theory is the belief that if people adopt this view, they will become more tolerant of others.

Cyberneticians have distinguished the recent work in cybernetics on constructivist epistemologies from the earlier work on control systems by using the term "second order cybernetics." This term was first used by Heinz von Foerster who defined first order cybernetics as the cybernetics of observed systems, whereas second order cybernetics is the cybernetics of observing systems (Von Foerster, 1979). Von Foerster intends the term "observing systems" to be interpreted in two ways -- either systems which observe or the act of observing systems. Gordon Pask made a similar distinction when he defined first order cybernetics as dealing with the purpose of a model, whereas second order cybernetics deals with the purpose of the modeler. Francisco Varela suggested that first order cybernetics is concerned with controlled systems, whereas second order cybernetics is concerned with autonomous systems.

I have proposed two additional conceptions of second order cybernetics (Umpleby, 1979). First order cybernetics can be said to be concerned with interactions among the variables in a system, whereas second order cybernetics is concerned with the interaction between the observer and the observed. The final definition goes beyond the one-brain problem of psychology or artificial intelligence and focuses instead on the n-brain problem of communities or societies. First order cybernetics can be illustrated by theories of social systems, whereas second order cybernetics deals with the interaction between ideas and society. For a summary of the definitions of first and second order cybernetics, see Table 1.

Table 1. Definitions of First and Second Order Cybernetics

AUTHOR	FIRST ORDER CYBERNETICS	SECOND ORDER CYBERNETICS
Von Foerster	the cybernetics of observed systems	the cybernetics of observing systems
Pask	the purpose of a model	the purpose of a modeler
Varela	controlled systems	autonomous systems
Umpleby	interaction among the variables in a system	interaction between observer and observed
Umpleby	theories of social systems	theories of the interaction between ideas and society

Contemporary cybernetics and the philosophy of science at times seem to some people to be at odds. In particular, scientists often have difficulty understanding what cyberneticians are saying. One way to understand why is to compare the assumptions underlying cybernetics with the work in philosophy on informal fallacies. The informal fallacies have no rigorous philosophical foundation. They are simply a set of guidelines or "rules of thumb" intended to help people formulate sound arguments.

Morris Engel (1980) has identified twenty-five informal fallacies, but he is quick to note that no two texts are likely to contain the same number of fallacies. He groups the fallacies into three categories:

1. Fallacies of ambiguity which involve problems with language.

2. Fallacies of presumption which are concerned with errors in thought.

3. Fallacies of relevance which raise emotional considerations.

At least three fallacies -- one in each category -- appear to rule out a key tenet in cybernetics.

One of the fallacies involving language is the fallacy of accent, which results from confusion about context. Examples given by Engel are the saying, "You never looked better"; the remark, "I wish you all the good fortune you deserve"; the Federal regulation, "Warning: Under Title 18 of the U.S. Code it is a Federal offense to assault a postal employee while on duty"; and the czar's reply to a prisoner's plea for a pardon, "Pardon impossible to be executed." The fallacy of accent is an attempt to label as impermissible, or at least confusing and therefore poor form, certain types of linguistic constructs. One way of confusing context is to shift levels of analysis. Self-referential statements entail at least two levels of analysis. Hence, any scientific theory which attempted to take account of self-referential statements would seem to be ruled out by the fallacy of accent.

Within the fallacies involving thought is "begging the question" which is given as an example of evading the facts. One form of begging the question is to argue that A is so because of B, where B is dependent on A. Examples given by Engel are a quotation from a textbook, "Every statement in this book is true. And the authority for this is that the statement `Every statement in this book is true' is in fact a statement in this book"; the comment, "The crime this man committed is the result of his childhood environment; for all such crimes are rooted in childhood environment, as this man's case proves"; a statement from a philosophy essay, "Reality in itself must be as it appears to the five senses; for if it were not, then there would be no other way that we could know it"; and the summary of a contemporary philosophical position, "Moral beliefs are unjustifiable because they are not verifiable in sense experience." The definition of this fallacy given by Engel would seem to rule out circular causality. The examples he gives often combine circular reasoning with confusions of context. But circular causality is fundamental to cybernetics.

Among the fallacies of relevance, which raise emotional issues, is the ad hominem fallacy. Engel lists the ad hominem fallacy as an example of fallacies involving personal attack. Examples given by Engel are the following: "As a manufacturer you should have supported this bill urging higher tariffs." "Of course you would be in favor of reduced real estate taxes because you would benefit personally by such a reduction." "One cannot believe the arguments of conscientious objectors, since they are obviously trying to escape the draft." The ad hominem fallacy suggests that it is an error to shift the focus of attention from a statement to the person who makes the statement. However, second order cybernetics claims that it is not fallacious but rather appropriate to focus attention on the observer.

Cyberneticians, therefore, encounter difficulty in each of the three main groups of informal fallacies. The issues they seek to deal with have been associated with abuse of language, sloppy thinking, and emotional appeals. Perhaps we should not be surprised that so many scientists find it difficult to embrace contemporary cybernetics. Cyberneticians not only must explain their ideas, they must also overcome their listeners' previous schooling. Apparently the time has come to question the unstated epistemology underlying the informal fallacies and to propose a new set of guidelines to assist in constructing useful statements.

However, the conflict between cybernetics and the philosophy of science is not limited to the informal fallacies. Particularly if one is interested not only in cognition but also in social systems, two additional problems arise.

In the classical philosophy of science theories were presumed to have no effect on the systems they described. It was reasonable to assume that atoms did not behave differently after physicists adopted the quantum theory. However, there is clearly an interaction between social theories and social systems (Soros, 1987). Economic systems changed when people acted on the theories developed by Adam Smith, Karl Marx, John Maynard Keynes, and Milton Friedman. In fact the desire to change social systems is usually a principal reason for developing social theories. Cyberneticians feel quite comfortable with the dialogue between ideas and society. Indeed this phenomenon can be viewed as an example of circular causality, self-reference, and the role of the observer. An even more extreme example of the interaction between theory and phenomenon would be the evolution of theories that describe the evolution of ideas.

Another point of disagreement between the philosophers and the cyberneticians is over what Popper called the unity of method. Popper claimed that the methods developed for the physical sciences can and should be used for the social sciences as well. However, social systems, unlike physical systems, are composed of thinking participants. Efforts by one observer to predict the behavior of a social system, for example a stock market, are complicated by the fact that all other observers are trying to do the same thing. Social systems are composed of thinking participants whereas physical systems are not. Hence, simply prescribing a unity of method is an inadequate resolution of the differences between the physical and social sciences. An alternative resolution is proposed in the next section. (Table 2 contains a summary of the three philosophical positions which have so far been described -- the classical philosophy of science with Karl Popper as a leading example, the sociological approach to science with Thomas Kuhn as a leading example, and contemporary cybernetics which represents a biological approach to knowledge and embodies a constructivist epistemology.)

Table 2. Summary of Three Philosophical Positions

POPPER	KUHN	CONSTRUCTIVIST CYBERNETICS
a normative view of epistemology: how scientists should operate	a sociological view of epistemology: how scientists in fact operate	a biological view of epistemology: how the brain functions
non-science vs. science	steady progress vs. revolutions	realism vs. constructivism
solve the problem of induction: conjectures and refutations	explain turmoil in original records vs. smooth progress in textbooks	include the observer within the domain of science
how science as a picture of reality is tested and grows	how paradigms are developed and then replaced	how an individual constructs a "reality"
scientific knowledge exists independent of human beings	even data and and experiments are interpreted	ideas about knowledge should be rooted in neurophysiology
we can know what we know and do not know	science is a community activity	if people accept this view, they will be more tolerant

RECONCILING CYBERNETICS AND SCIENCE

Criticisms of the applicability of science to social systems have become widespread (Morgan, 1983). Many writers have concluded that those who study social systems should reject science. However, science is not an immutable structure. It was invented by human beings, and it continues to change as scientists venture into new areas of inquiry, such as social systems.

The classical view of science includes a description of how theories change to incorporate new ideas. The procedure is called the correspondence principle. It was first used by Niels Bohr during the development of the quantum theory. The idea is that any new theory should reduce to the old theory for those cases in which the old theory is known to hold. Hence, the old theory becomes a special case of a new, larger theory when a newly defined dimension reduces to zero.

To illustrate the point, consider an example from chemistry. The gas laws were based on the assumption that gas molecules had no diameter, that they were essentially point masses. This assumption worked well for many decades. However, when technology improved, gases could be compressed until their diameters became significant. The gas laws had to be rewritten, taking into account the diameters of the molecules.

When new theories are constructed in accord with the correspondence principle, science appears to advance in a well-ordered fashion. An advantage of theories so constructed is that all of the evidence which supported the old theory also supports the new theory. However, the correspondence principle is a key element in the thought patterns of only one faction of those who study the history of science.

Among historians of science there has been a split between the sociologists, led by Kuhn, who claim that old and new theories are incommensurable, and the philosophers, who maintain that by using the correspondence principle it is possible to identify an orderly progression of scientific knowledge. I believe that these two ideas can be combined. There are two transitions -- from normal science to revolutionary science and from revolutionary science to normal science (see Figure 1). Kuhn emphasized the transition from normal science to revolutionary science through the emergence of incommensurable ideas. Popper, Krajewski and others describe transitions from old theories to new theories through the correspondence principle. I would call the transitions that use the correspondence principle examples of the second type of transition from a revolutionary period to a new period of normal science. The sequence of mental constructions -- normal science, scientific revolution, normal science -- is very similar to Hegel's concept of dialectics -- thesis, antithesis, synthesis.

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NORMAL    ---------->    SCIENTIFIC     ---------->    NORMAL
SCIENCE       |          REVOLUTION          |         SCIENCE
              |                              |
     INCOMMENSURABLES             CORRESPONDENCE PRINCIPLE

Mass, length and time             The Lorentz transformations
are fixed or variable
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Figure 1. The Dialectics of Relativity Theory

Consider two examples -- relativity theory and constructivist cybernetics. In the case of relativity theory the transition from normal science to revolutionary science was marked by a dramatic shift in assumptions about mass, length, and time. In Newtonian physics mass, length, and time were fixed. In relativity theory mass, length, and time vary. Some scholars emphasize the incompatibility of the old and new theories. Others emphasize that using transformations originally proposed by Lorentz it is possible to show that the relativistic equations for mass, length, and time reduce to Newtonian equations when the relative velocity is small. By taking into account the additional consideration of relative velocity, the old theory can be regarded as a special case of the new theory. Although the Newtonian world view did include attention to relative velocity, relative velocity did not alter mass, length or time. Using the correspondence principle, the old theory becomes an instance of the new theory when a newly defined or newly interpreted dimension is very small.

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NORMAL    ---------->    SCIENTIFIC     ---------->    NORMAL
SCIENCE       |          REVOLUTION          |         SCIENCE
              |                              |
     INCOMMENSURABLES             CORRESPONDENCE PRINCIPLE

Distinctions between first
and second order cybernetics      Amount of interaction
                                  between observer and
Apparent contradictions           observed
between cybernetics and
the informal fallacies
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Figure 2. The Dialectics of Constructivist Cybernetics

In the case of cybernetics, for several years cyberneticians have emphasized the differences between first order cybernetics and second order cybernetics (see Figure 2). It has become routine at cybernetics meetings to distinguish the new cybernetics perspective of constructivism from the conventional scientific view of realism. Efforts to define the incommensurability of these two perspectives mark a transition from normal science to revolutionary science. I believe that the new revolutionary view is now well defined and that further progress requires entering a new period of "normal science." In order to make the transition from revolutionary science to a new period of normal science, it is necessary to define a new dimension or reinterpret an old dimension. Such a dimension could be "the extent to which the characteristics of the observer alter descriptions of the observed" or, more briefly, "the amount of interaction between observer and observed" (see Figure 3).

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------------------------------------------- second order
|                                         | cybernetics or the
|  ------------  classical science        | new epistemology
|  |           |                          |
|  |     ------|--------------------->    |
|  |           |  amount of interaction   |
|  ------------  between observer and     |
|                observed                 |
-------------------------------------------
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Figure 3. An Application of the Correspondence Principle

There are two implications of this perspective. First, constructivist cybernetics -- and similar ideas developed in other disciplines under different names -- can be interpreted as creating a scientific revolution just as relativity theory created a scientific revolution. The new revolution is of great importance because the new dimension of interaction between observer and observed affects not a single scientific field but all of science. Second, it is now possible to make connections between the social sciences and the natural sciences. Rather than having the social sciences and natural sciences continue to develop independently of each other, we are now in a position to describe more clearly how these two branches of science are similar and how they are different.

CONCLUSION

I believe that these ideas allow us to resolve the tension that has existed between science and cybernetics in recent years. This tension can be viewed as an example of the transition from a period of normal science to a period of revolutionary science. I propose that we resolve the tension by moving from the current period of revolutionary science to a new period of "normal science." In order to make this step we need to redefine or expand science by adding the dimension of interaction between the observer and the observed. By doing so we preserve the admirable traditions of the philosophy of science. Given the investment of time and effort already made in developing the philosophy of science, modifying it, rather than creating a totally new alternative, is more likely to be successful in the near future. A further benefit of modifying rather than rejecting the philosophy of science is that rather than having a gap between our knowledge of the physical world and our knowledge of the social world, we have instead a single conceptual structure with well-defined connections among the various fields of knowledge.

If we resolve the apparent contradictions between science and second order cybernetics in this way, I believe that we show two things. First, cybernetics is compatible with the most fundamental traditions of science and hence can be regarded as a part of science. Second, we demonstrate the "cybernetics of science." Cybernetics was originally defined by Wiener (1948) as the science of control and communication. By modifying and enlarging science we control its content and communicate its basic values to an additional group of scholars -- those who have criticized the adequacy of the classical conception of science for dealing with social systems.

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