VIEWS OF KNOWLEDGE AND SYSTEM DYNAMICS: AN HISTORICAL PERSPECTIVE AND COMMENTARY

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Abstract

Views of knowledge contain methodological theories--theories of how knowledge progresses--and epistemological theories--theories about the nature of knowledge. The former serve four particularly important functions: providing formulas for the generation of knowledge, criteria for the legitimation of knowledge, reasons to suspect other ideas, and rules for the propogation of ideas.

Historical Perspective: The views of knowledge important for system dynamics and its major competitors--namely, paradigmism for system dymanics, probabilism and instrumentalism for econometrics and its variations--are traced historically to roots in Francis Bacon's inductivism. All three views are solutions offered to the crisis created in inductivism by the recognition that knowledge is not Truth.

Commentary: Probabilism and instrumentalism, often employed in econometrics and its variations, encourage the search for new correlations of data and hence can sometimes lead to theoretical progress. But the tendency to exclude real-world models seriously hinders the theoretical progressivity in those fields by rendering its theories much less vulnerable to error. Paradigmism in system dynamics aids theoretical progressivity by encouraging the generation of real-world models and hence vulnerability to error, but the most popular interpretation of Kuhn's paradigmism also has dogmatic and elitist implications that can compromise theoretical progressivity and encourage a cultish rather than an open atmosphere in system dynamics. Refutationism, a view of knowledge developed in detail over the past half-century, is the view of knowledge used when system dynamics is at its best. It captures and improves upon the benefits of paradigmism for system dynamics while excluding the deleterious consequences of paradigmism on system dynamics. The essay closes by opening the door to refutationism and recommending that system dynamicists consciously adopt it as their view of knowledge.

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INTRODUCTION

"Nothing is stronger than habit."
(Ovid, 43 B.C.- 18 A.D.)

There is a tale about a devout tribe of natives isolated by the jungles of Brazil. Torrential rains had flooded their lands devestating their homes, crops, and livestock. Starving and without shelter, they reverently climbed a sacred hill to implore their gods for mercy. During the ceremony, when all eyes were searching for an omen, a relief plane came up from the southern horizon. They watched in awe as the soundless, tiny speck grew to a roaring giant above their heads. As the plane dropped packages of food and tools, the natives bowed in subservience to their savior.

With solemn faith the tribe erected a crude replica of their new, merciful god, and with the tenacity of unquestioning believers, repeated the ceremony to their totem day after day, month after month-- always expecting him to reappear with another cargo.

Although distant from us, both literally and culturally, this tribe is not actually so foreign. We all have certain rituals which we believe will deliver cargo. Anthropologists have coined the phrase <u>cargo cult</u> to denote a group that believes proper rituals will produce proper results.

This essay focuses on a specific type of ritual and cargo. The rituals are guided by theories of how knowledge progresses and the cargos desired are determined by theories about the nature of knowledge. To say the same using other terminology, the rituals are guided by <u>methodological theories</u>--theories of how knowledge progresses--and the cargos are determined by <u>epistemological theories</u>--theories about the nature of knowledge. A <u>view of knowledge</u> is always constituted of a methodological element and an epistemological element.

Methodological theories and epistemological theories are related to each other. There can be no complete understanding of how knowledge progresses without a discussion of what is to progress. Theories about the nature of knowledge always entail constraints on how it can be discovered and advanced.

People in system dynamics, like those in most intellectual communities, hold a view of knowledge. Indeed, those in system dynamics form a "knowledge cult" of sorts, with consequences that are shared by most knowledge cults. First, and most importantly, the view of knowledge in system dynamics promises results. If the system dynamics view of knowledge is employed correctly, according to its adherents, certain crucial problems are amenable to better solutions than those promised by other views, and some problems not soluble by other views are soluble by using the system dynamics view. Second, the view of knowledge is constantly under revision. People in system dynamics expend a sizable amount of effort attempting to understand and improve their view of knowledge, effort which hopefully will make system dynamics a more powerful and far-reaching tool.

For a knowledge cult, views of knowledge often become rigid theological mandates, even in the face of improvement, and often provide the weapons for battle between different cults. When the skirmishes focus upon comparison of the problem-solving power of different views of knowledge (consequence one above), and/or upon improvement of the problem-solving power of different views of knowledge (consequence two above), they cannot help but be beneficial. Unfortunately, however, the battles often turn into war, marked by the exchange of cultish aphorisms and dogmatic mandates with little benefit to anyone.

This essay has two broad goals: to provide a historical perspective on the views of knowledge important to system dynamics and its principal competitors and a commentary from that perspective. The historical perspective will show that the probabilism and instrumentalism of econometrics and its relatives, as well as the paradigmism of System Dynamics, are the offspring of Francis Bacon's inductivism. All three views provide solutions to the crisis created by a major epistemological shift in Baconianism: from the belief that knowledge is Truth to the realization that it is not Truth.[1] The commentary will have three different foci: (1) To sharpen the arguments for and against probabilism and instrumentalism, the views of knowledge assumed in econometrics. (2) To pinpoint difficulties into which System Dynamics might be led by paradigmism. (3) To show how System Dynamics can, should, and is beginning to move beyond paradigmism to a better view of knowledge: knowledge as conjectures and refutations.

II. FUNCTIONS OF METHODOLOGICAL THEORIES

> "The people turn to a benevolent rule
> as water flows downwards, and as wild
> beasts fly to the wilderness."
> (Mencius, 372-289 B.C.)

Although views of knowledge have both a methodological and an epistemological element, the historical perspective outlined will focus largely on methodological theories. The concentration on theories of how knowledge progresses is not intended to indicate that theories of the nature of knowledge are

1. The capitalized "T" in "Truth" indicates reference to an absolute truth.

unimportant. The reason for concentrating upon methodological theories is that probabilism, instrumentalism, paradigmism, and refutationism all have one common epistemological root: knowledge is not Truth. The different methodological alternatives to that common root have been very important to the camps of system dynamics and its rivals.

Before embarking upon the historical journey, however, a concentrated discussion of the various functions of methodological theories would be helpful. The influence of methodological theories on intellectual communities is vast. The topology below will outline the most significant directions of that influence.

A. Four Functions

Methodological theories help generate knowledge, legitimate ideas, render other ideas suspect, and propogate ideas to others. Each of the four functions--generation, legitimation, suspicion, and propogation--are illustrated below by contrasting two well known methodological views: induction and deduction.[2]

The first function of methodological theories is to provide a formula for generating knowledge. The inductivist, as a first step in gaining knowledge, collects facts through observation. Only after exhaustively collecting empirical data will he attempt to induce ideas from the facts, and even then he will be skeptical of his thought processes.

Unlike his opposite, the deductivist believes that the first stage in

2. "Induction" and "deduction" are the methodological components of "empiricism" and "rationalism," respectively. The latter two terms refer directly to epistemological theories--"knowledge consists of facts" and--"knowledge consists of ideas"--but they often are taken to include the methodological components. A distinction between the methodological and epistemological components is necessary for clarity in this essay.

generating knowledge is to think. Knowledge is the jewel of precise and clear thoughts. Treating facts and observations with suspicion, he approaches them reluctantly, using them only to clarify his ideas. If there is conflict between the facts and his ideas, he tends to trust the latter.[3]

The second function of methodological theories is to legitimate ideas. The inductivist claims legitimacy for his ideas because they are based on facts, and, therefore, he labels them <u>scientific</u>. The deductivist legitimates his ideas, not on the basis of empirical research, but on the precision of his thinking and the intrinsic clarity of his ideas. He, too, labels his ideas scientific. Each methodological theory accords scientific status only to ideas that are legitimated by its own criterion.

A corollary of the legitimating function is the third function of methodological theories: suspicion is created of ideas generated by or legimated by other methodological theories. Inductivists quickly attack ideas not thoroughly grounded in observation. Thinking is dangerous and extended contemplation is particularly debilitating. Deductivists, on the other hand, are unimpressed with inductivist claims to scientific status; facts are misleading, and ideas rooted in them are just as suspect.

It is not surprising that intellectual dialogues between inductivists and deductivists are sometimes barren. A claim to science by one is often an invitation to suspicion for the other. One classic debate between inductivist followers of Newton and deductivist followers of Descartes provides an example.

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3. Methodological theories have influences that extend far beyond intellectual work, affecting our personal, social, and political lives. See Section VII-A (3), and the footnote there.

Newtonians emphasized that there was a measurable force between masses--gravitation--and that the force was a fact. Whether the force acted through empty space or required an ether for its propogation was debated, but the fact that gravitation existed was beyond dispute. Cartesians, on the other hand, deduced that there could be no gravitational force from their thesis that all motion results from pushes. The "fact" of gravitation, which merited scientific status for the Newtonians, was rendered suspect by the deductions of the Cartesians.

Propogation is the fourth function of methodological theories. The inductivist mandate for propogation is quite simple: encourage everyone to observe the facts. An indoctrination into inductivism is a factual baptism: an absolution of preconceived notions and a new start--based on facts. Books, reports, and other presentations by inductivists begin with research findings. Conjectures and speculations are confined to a secondary role and appear, if at all, at the end. Even there, they are introduced by cautionary warnings and even apologies.

Deductivists propogate their ideas by invoking one's abilities to think clearly and draw conclusions validly. Like inductivists, they ask that preconceived ideas and prejudices be discarded. Their appeal, however, is to one's intuition and common sense, not to the facts. Most deductivist books and reports commence with axioms followed by deductions. As a preamble there is sometimes an attack on other ideas to show them unclear, inconsistent, or in conflict with intuition or common sense.

There are many other methodological theories besides inductivism and deductivism. The views of knowledge discussed in this essay--inductivism, probabilism, instrumentalism, paradigmism, and refutationism--each has a methodological theory. Regardless of the particular methodological theory, however, the same four functions are served.

B. Priority of the Functions

Generation and legitimation are preeminent functions. Arguments in support of or against a view of knowledge usually turn upon how well its methodological component is performing these functions, and views of knowledge should rise and fall according to the success of the methodological component in performing those functions.

Suspicion and propogation are epiphenomenal functions, being the effects of the first two. Nevertheless, these functions affect the relations between competing knowledge cults. At stake is the ability of an intellectual community to accept and learn from external criticism, and its effectiveness in teaching and winning acceptance for its ideas. A history encompassing the third and fourth functions would be replete with secret intrigues, heretical expulsions, and other scandalous episodes. Although such tales are spicy and absorbing, this essay will focus on the principal functions of generation and legitimation. The third and fourth functions will not be completely ignored, however. Section VII-C will include a discussion of suspicion and propogation difficulties in paradigmism.

III: THE HISTORICAL HERITAGE

> "There are and can be only two ways of searching into and discovering truth. The one flies from the senses and particulars to the most general axioms...this way is now in fashion. The other derives axioms from the senses and particulars, rising by a gradual and unbroken ascent, so that it arrives at the most general axioms last of all. This is the true way, but as yet untested." (Francis Bacon, Novum Organum, 1620)

A. Francis Bacon's Revolution in Scientific Method

Francis Bacon (1561-1626), Lord Chancellor under James I of England, distinguished himself in law, literature, politics, and philosophy. Perhaps his greatest contribution, however, was a new theory of how to seek and advance knowledge.

The centers of learning in England during Bacon's era were universities, the strongholds of Catholic thought. Even though the Anglican Church had already been formed under the tumultuous reign of Henry VIII, both Cambridge and Oxford still thrived as Catholic centers. During this period, when it was fashionable to blame the Catholic Church for nearly all that seemed authoritarian and degenerate, Bacon condemned Catholic theology in general and its Aristotelean roots in particular for stifling the growth of knowledge.

In such works as Advancement of Learning (1605) and Novum Organum (1620) Bacon argued that natural philosophy--science--had progressed little since ancient times. He saw no merit in speculative philosophy, contending that in some respects modern thinkers knew less than the Greeks.

Not all modern men were lost to metaphysical speculation. Bacon admired the revolutionary discoveries of Copernicus and Galileo, marvelled at the explorations of Marco Polo and Magellan, and appreciated such inventions as the printing press and gunpowder.

Contrasting the lack of progress by speculative thinkers to the remarkable gains of others, Bacon posed himself a question: what demarcates speculative thinking from progressive thinking? His answer can be summarized in two parts.

First, lack of progress in the Catholic tradition was due to speculation about essences. Aristoteleans believed that the universe consists of essences. Bacon contended that statements about essences reflect subjective belief and not objective reality. As a result, Aristotelean science amounted to idle conjectures about the definitions of concepts, and Aristotelean ideas had reference to the real world only by accident. Progress could not be made by speculation.

Second, progress necessitated observation of material facts. The facts could not be related to Aristotelean intuitions. Instead, they would have to be located in the world outside ourselves. In sum, progress would be made by avoiding speculation and observing facts.

Now, there is a place for thinking in Baconian method. After the fact-gathering stage of science there is to be an idea-extracting stage. This is induction: extrapolating general ideas from specific facts.

Bacon's methodological theory provides a legitimation criterion for deciding which ideas are scientific and which are not. Since all scientific ideas must be inductions from facts, all scientific ideas must be reducible to facts. Ideas not reducible to facts are not legitimate. Since Bacon's time methodological theories which assume that general ideas are generated from facts and/or are reducible to facts have been called inductivist methodological theories.

Incidentally, Aristotelean ideas are reducible, but to essences and not to facts. Essences are subjective intuitions according to Bacon, as we have already seen. Hence Aristotelean ideas are not scientific by the inductivist legitimation criterion.

The crucial epistemological element in Bacon's view of knowledge is that knowledge is Truth, not speculation. His inductive method was a tool to deliver the cargo, a means of guaranteeing that Truth would be found. He reasoned that if facts in the real world are beyond question, and scientific ideas are induced from facts, it follows that scientific ideas must also be beyond question, i.e., that scientific ideas are Truth.

Aristotle also believed that knowledge is Truth. Science consisted of correct statements about essences. Since essences were the substance of the universe, correct statements about them must be Truth. Bacon would probably have thought that the Aristoteleans, in their attempts to have the Truth delivered, resembled the natives in the tale which opened this essay.

Not just Aristotle and Bacon, but most philosophers and scientists up to the turn of the twentieth century believed that science is Truth. Exceptions are the irrationalists, who do not believe in a consistent Truth (Heraclitus, Hegel, and their followers), and those who believe in Truth but feel that people can only conject about it (Xenophanes, Popper and their followers). If the arguments of other pre-twentieth century thinkers led to the conclusion that science is not Truth, they either questioned their own reasoning or invoked a supernatural being as guarantor of Truth. Isaac Newton, perhaps the most influential scientist of all time, did both.

Ironically, science is not Truth. Some, such as Heraclitus and Xenophanes, had sensed that from time immemorial, but it has only been since the early decades of the twentieth century--with the overthrow of Newtonianism and the establishment of relativity theory and quantum principles--that the new view has been widely accepted.

Despite advantages over Aristotelean disputation, inductivism was severely criticized and its shortcomings exposed. The attacks were crucial for the development of probabilism, instrumentalism, and paradigmism, but before investigating them we should understand why inductivism became so highly regarded and widely accepted.

B. The Newtonian Fortress Protects Inductivism

A coincidence of circumstances surrounding and including Isaac Newton's physics allowed inductivism to become the predominate methodological theory by the late seventeenth century and sustained it through the nineteenth century. The sweeping success of Newton's dynamics and celestial mechanics, the adoption of inductivism by the Royal Society of London, and the anti-Catholic mood in England all conspired to establish Baconian method as the deliverer of Truth.

The story is typical. A methodological theory believed to have produced successful research is accepted widely. Whether or not the methodological theory actually produced the research program is seldom asked. Even valid criticism is little noted until the research program has run its course and/or is replaced by another research program. Only then are the criticisms removed from storage and loudly trumpeted, contributing to the disintegration of a methodological era.

Sixty-one years after Bacon died, Isaac Newton published his Mathematical Principles of Natural Philosophy (1687). It outlined a system of dynamics and celestial mechanics which were corroborated on all fronts. Almost everyone believed that Newton's physics was Truth. Further, Newton's success was credited to his adherence to inductive method. The promised cargo--Truth--seemed to have been delivered. What more could be asked of a methodological theory!

Even before publication of Newton's Mathematical Principles, Baconian method had received a most significant endorsement: The Royal Society of London had adopted it as the proper and official formula for the advancement of knowledge. The Royal Society, one of the first scientific institutes, had been founded independent of university influence. An institution free of Catholic domination was believed crucial for the advancement of knowledge. As a fledgling group organized by such men as Robert Boyle, it passed through infancy in the unsettled times of the Civil War, the Protectorate under the Cromwell's, and the Restoration under Charles II, to become one of the most prestigious scientific institutions in the world.

By the eighteenth century, Isaac Newton had become the most famous and revered member of the Royal Society. Since the Royal Society had adopted Baconian method as its official formula for advancing knowledge, Newton's work appeared as the product of induction. Despite Newton's known reservations about the viability of Baconian induction, and despite his belief that Bacon was not very clever, the public commonly believed that Newton had used induction.[4] Even the Royal Society, basking in the fabulous success and acclaim shining on Newton, did little to discourage the misconception.

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4. Students of Newton's life and work do not believe that he used induction to generate his ideas. His law of gravitation far transcended observable instances from which the law was supposedly induced. Newton talked of gravitational forces between entities that man had never, and might never, be seen. Furthermore, use of Bacon's legitimation criterion--ideas are scientific if they are reducible to facts--would have rendered Newton's law of gravitation non-scientific. Gravitation cannot be touched or seen, and it has the strange quality of acting at a distance. In addition, the biographical fact that Newton held little respect for Bacon's ideas--at least privately--would not make it plausible to assume he used Bacon's ideas.

C. Hume and Whewell

Two profound critics of inductivism during the era of Newtonian successes were David Hume (1711-1760) and William Whewell (1794-1866). Hume's attacks provided the arguments which led to probabilism. Whewell's historical and psychological analyses, which were very similar to those of Thomas Kuhn over one century later, are behind another alternative: paradigmism. Instrumentalism, although it did not evolve directly from inductivism, is indeed closely related and oftimes includes probabilistic methodology. Probabilism, paradigmism, and instrumentalism--three views of knowledge with methodological components important for system dynamics and its alternatives--can thus be interpreted as outgrowths of the work of Hume and Whewell. More specifically, all three methodological theories provide solutions to problems in inductivism that were created by an epistemological crises: the realization that knowledge is not Truth. Arguments of Hume and Whewell were paramount in creating the crisis and generating the three most widely held solutions to it. Their arguments have been used by others--even discovered independently by others--but the arguments themselves have remained the same. The final view of knowledge to be considered in this paper--knowledge as conjectures and refutations--provides yet another solution to the crisis, as well as new arguments against inductivism along with severe attacks on probabilism, instrumentalism, and paradigmism. Refutationism does share with the other three that one cricial epistemological stand: knowledge is not Truth.

D. Hume Attacks with Logic

"Never literary attempt was more unfortunate than my Treatise of Human Nature.

It fell dead-born from the press."
(David Hume, My Own Life, 1777)

Initially David Hume, like nearly all his contemporaries, assumed that Newton's dynamics and celestial mechanics were Truth. He also assumed that inductive method had delivered the dynamics and celestial mechanics. After comparing these two assumptions, however, he found them inconsistent. When Hume's A Treatise of Human Nature was published in 1739, intellectuals gave it a very cold reception. We should not be surprised. His attacks threw doubt on two most cherished beliefs: the Truth of Newtonian physics and the validity of inductive method.

Hume argued that Newtonian physics presupposes a universal law of causality: for every event there is a cause. But, his reasoning continued, no one can be sure that in the future the same causes will lead to the same effects, or "facts." Hence future "facts" can only be inferred with a degree of probability. Hume concluded that (1) either Newtonian physics, if it originated in and is legitimated by inductive method, cannot be True knowledge; it can be highly probable at best; (2) or inductive method is not entirely valid; (3) or both (1) and (2).

Hume did make a hesitant choice between the two pillar beliefs. He put his faith in inductive method and, at the same time, declared Newtonian physics highly probable.

The view of knowledge attached to Baconian induction had changed forever after Hume's analysis. The crucial epistemological element of Baconian induction--that knowledge is Truth--could not be supported. Hume's attack led to a fallback position of inductivism: facts can generate ideas that are probable, but not certain; legitimate ideas are reducible--within a reasonable degree of probability--to the facts. Inductivism had given birth to probabilism. Hume was the midwife.

E. Whewell Analyzes Inductivism

> "The examination of the steps by which our ancestors acquired our intellectual state, may make us acquainted with our expectations as well as our possessions, may not only remind us of what we have, but may teach us how to improve and increase our store. (William Whewell, History of the Inductive Sciences, 1837)

Nearly one century afte Hume's attacks, William Whewell (pronounced "Yule," as in "Yule Tide") put forth historical and psychological arguments against inductivism. Like Hume's work, his major essays, History of the Inductive Sciences (1837) and Philosophy of the Inductive Sciences (1840), set forth unpopular theses.

In his studies of the history of science and psychology of discovery, Whewell found that the processes of advancement did not resemble the research and induction stages prescribed by inductivism.[5] Scientists, he found, made bold guesses and then tested them against facts. Most of the guesses turned out to be mistaken, but a few were correct. Even correct ideas, however, could not be proclaimed the Truth; they very well might be found mistaken later. Whewell argued that freedom in thinking and a vivid imagination were important elements in the guessing and the testing.

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5. Whewell confuses terminology frequently. An example: Although his theses about the progress of science are clearly non-inductive, he lables sciences the "inductive sciences." De Morgan, the famous logician, found Whewell's terminology so misleading that he chastized Whewell severely.

Although facts seemed unimportant for generating knowledge, Whewell did maintain that they are significant for legitimating knowledge. When an idea had helped a scientist understand phenomena, he would then deduce the pertinent facts to confirm the idea. If the facts were there as expected, the idea would be legitimate. Unlike inductivism, however, legitimate ideas are not totally reducible to known facts. According to Whewell, ideas colligated into an intelligible whole usually entailed facts which had been unforeseen.

Whewell's challenge to Baconian induction was clear: inductive method could not adequately explain either the generation or the legitimation of knowledge. On the other hand, his view of knowledge shared with probabilism the epistemological thesis that knowledge is not Truth and it provided another solution to the crisis created by that epistemological thesis. Whewell's view of knowledge is, as we shall see in Section VI-B, very similar to an interpretation of Thomas Kuhn's view of knowledge. The name Whewell should be associated with the founding of paradigmism.

F. Inductivism Repels the Attacks

Despite the attacks by Hume and Whewell, inductivism did not surrender. The belief that Newtonian physics was the product of inductive method, along with the unprecedented success of the Newtonian research program, made a strong fortress. The only visible alteration was the fallback to probabilism. While probabilists admitted that facts could not guarantee truth, but only likelihood, they maintained other basic ingredients of inductivism: that ideas are generated by induction from facts and that ideas are legitimated by reduction--within a reasonable degree of probability--to facts. Whewell had indeed planted seeds for paradigmism, but those seeds remained in germination for over a century. Thomas Kuhn finally sprinkled water on them in the early 1960's, after which time paradigmism grew rapidly.

In any case, Newtonian physics stoutly defended the harrassed inductivism. Although the outer wall had been breached, the inner fortress remained. At the turn of the twentieth-century, when Newtonian physics itself began to falter and was finally trampled by the new theories--in relativity and quantum phenomena--inductivism was sacked and destroyed. Before telling the story, however, we need to look at an important refinement in probabilism contributed by Thomas Bayes.

IV: PROBABILISM: THE FALL BACK POSITION OF INDUCTIVISM

> "Given the number of times in which an unknown event has happened and failed: Required the chance that the probability of its happening in a single trial lies somewhere between any two degrees of probability that can be named."
> (Thomas Bayes, opening lines from "Essay Towards Solving a Problem in the Doctrine of Chances," 1763).

A. Thomas Bayes Refines Probability Theory

Although Hume's A Treatise of Human Nature was received without enthusiasm in 1739, twenty-four years later the situation was quite different. Many scientists had already accepted that facts could generate ideas which were probable, and that ideas were legitimate if the facts rendered them a high degree of probability.

Interestingly enough, initial foundations for probability theory came

from across the Channel. Such books as Abraham de Moivre's The Doctrine of Chances (1718) and Jacques Bernoulli's Ars Conjectandi (1713) had already laid out the principles for inferring the probability of a sequence given the probability of a single event. However, tools for measuring the probability of an outcome in light of prior knowledge were not yet available. To make such tools was the goal of Thomas Bayes in his famous "Essay Towards Solving a Problem in the Doctrine of Chances" (1763).

To calculate the probability of a given outcome based on prior knowledge, one needs to know--or at least assign--the prior probabilities; that is, the probabilities before the trials are made. Bayes outlined how formulas can be generated to use prior probabilities in combination with posterior probabilities--the probability, given the evidence and prior knowledge, that a given phenomenon would be observed. To this day the label "Bayesian" implies the use of prior probabilities in the calculation of probabilistic statements.

Bayesian techniques are widely used in econometrics, and especially in stochastic calculations. Use of Bayesian techniques, however, imposes basic difficulties that constrain problem-solving power. We should be familiar with those difficulties.

B. Some Uses and Limits of Probabilism

Bayesians, from the time of their namesake to the present day, have been confronted with two major difficulties: deciding which constituent factors affect a certain outcome and assigning prior probabilities to those factors. Below are examples of three outcomes to be calculated. For the first the difficulties are insignificant, for the second they are severe, and for the third they are overwhelming.

In simple game theory, establishing constituent factors and assigning prior probabilities offer no difficulties. For example, the constituent factors for winning a game of dice can be quickly isolated, and prior probabilities can be assigned with complete confidence. Even for complicated games, if the constituent factors and prior probabilities can be established, the probability of a given outcome is precisely calculable.

Let us investigate a more difficult problem. Suppose we want to calculate the probability that Prancing Prince will win the Kentucky Derby. If we have long experience and perceptive wit, we would isolate the factors that might affect the horse's chances of winning. Its history, the trainers, the weather, the condition of the track, the jockey to be carried by the horse, the distance of the race, the characteristics of the other horses in the race, etc., are all constituent factors, and we would have to assign a prior probability to each.

Clearly, the handicapper's task of isolating constituent factors is somewhat arbitrary. He undoubtedly would leave certain possible constituent factors out of his calculation, such as the possibilities that the horse will break a leg, or be shot dead by an overzealous spectator. Even after settling upon a selection of constituent factors, his assignment of prior probabilities would introduce a further margin for error.

Given the problem of predicting a horse's chance of winning a race, however, probability theory might be the best tool available. The tools of Bayesians are certainly crude, but they are much better than nothing. The tools can also be improved with time and experience.

Now let us explore a third type of problem. Suppose one wishes to calculate the probability that Newton's law of gravitation is true. The constituent factors would be every possible attraction of mass particles to each

other. After having isolated the constituent factors, a prior probability would have to be assigned to each of them. But isolating the constituent events or assigning probabilities is obviously impossible. For this type of calculation, probability theory would be barren despite the attraction of how exciting it would be if only we could use it for such tasks.[6]

When evaluating probabilism--or any other method--it is important to remember the types of problems for which it is effective. As we have already seen from the history of inductivism, however, methods are often applied indiscriminately.

C. Einstein Admirers Having Fun

At a university cocktail party, a jocose plasma physicist greeted his friend from the anthropology department.

"Hello, John" he said, "Do you know who is the second greatest physicist of all time?"

"The second greatest?"

"Of course; we all know that Einstein was the best."

"Well...ugh...I guess the second best would have to be Newton."

"Wrong! Einstein is both the first and second greatest."

Most everyone knows that Einstein's name is associated with the special and general theories of relativity. But few are aware that he did important work with statistical models of probability, forming a foundation for the development of quantum mechanics. It is for the latter contribution that Einstein's admirers call him the second greatest physicist of all time, and

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6. Refutationists argue that such calculations would still be unimportant for progress in science even if they could be made. See Section VII-B.

it is that same work which gave probabilism a solid start in science.

The acceptance of the theories of relativity to explain the macro-universe was swiftly followed, during the early decades of this century, by an interest in explaining the microuniverse of quantum mechanics. Einstein, Bohr, Heisenberg, and Schroedinger--leaders in the field--developed statistical models to summarize data and make predictions. Probabilism as a method took strong hold; the ultimate matter of the universe appeared to operate according to its principles.

D. Probabilism as a Cult

> "I shall never believe that God plays dice with the world." (Einstein, 1879-1955)

Had probabilism developed as a tool for working only on specific types of problems, it might not have developed into a cult. But probabilism suffered the same fate as inductivism. In the same way the success of Newtonian physics fostered and protected inductivism, the success of quantum mechanics fostered and protected probabilism.

Ironically, Einstein never did surrender to the probabilist view, even though his own work in applied probability theory had been a major factor in its development. Inductivism had ignored Newton and Einstein was ignored by probabilism.

V. PROBABILISTIC METHODOLOGY + POSITIVISTIC EPISTEMOLOGY = AN INSTRUMENTALIST VIEW OF KNOWLEDGE

> "Nothing at bottom is real--except humanity." (Auguste Comte, Systeme de Politque Positive, 1851-1854)

A. Bohr and Heisenberg

Classical probabilists do not maintain that knowledge is Truth, but they do believe that probabilistic statements are about "facts" and that those facts are connected to the real world. The early Einstein--Einstein before the establishment of the uncertainty principle--seemed to maintain such a position.

The assumption that facts connect us with the real world was challenged, however, during the high tide of quantum mechanics. Niels Bohr's correspondence principle, according to which a given quantum of electromagnetic emission corresponds to a difference in energy levels of an electron--linked a sizable amount of data that had accumulated in sub-atomic research. When Bohr's student, Werner Heisenberg, formulated his famous uncertainty principle--roughly formulated, the uncertainty of the position of an electron is proportional to the certainty of its momentum, and visa-versa--a totally new impasse arrived in the history of science. It seemed impossible that more precise knowledge of the electron could be gained because the measuring waves altered its position and/or momentum. Knowledge of an ultimate real world seemed unrealizable. This impasse fit very well with the positivistic epistemological theory: i.e., that scientific statements should contain no claims about a real world behind observable phenomena.

Probabilistic method still provided an important tool for describing observable phenomena, but the tool could now be interpreted as merely a conventional device for relating data. Add a conventional interpretation of scientific statements to a positivistic epistemological position and one has what is usually called an <u>instrumentalist view of knowledge</u>. Instrumentalists maintain that knowledge progresses by formulating broader and broader formulas to incorporate more and more data, but that those formulas are merely conventions--they make no claims about the real world.

The instrumentalist view of knowledge was not new to the intellectual world. Even August Comte (1798-1857), who coined the word "positivism," was not the first to espouse instrumentalism. Long before Comte, in the sixteenth century, Andreas Osiander, who wrote a preface to Copernicus' <u>De revolutionibus</u>, claimed of Copernicus' heliocentric view of the universe that there is no need for Copernicus' hypotheses to be true, or even resemble truth; it was sufficient that they should produce calculations which agree with observations.

B. Instrumentalism as a Fashionable View in Modern Science and Social Science

Unlike probabilism and paradigmism, instrumentalism was not a direct historical outgrowth of inductivism. It did so happen, however, that the Heisenberg uncertainty principle provided a reason to interpret probabilistic equations positivistically, and a flood of instrumentalism was the result.[7] It has been

7. Some attribute instrumentalist views to Bohr. Bohr, who eventually formulated his complementarily principle (not to be confused with his earlier correspondence principle), was not an instrumentalist, according to unpublished work by Michael Mulholland. Mr. Mulholland argues that Bohr actually was a realist, but that the two complementary views--waves and particles--led to consequences similar to those of instrumentalist.

a very fashionable view of knowledge in some sciences and social sciences ever since. Below are a few examples.

Physical chemistry since before the Second War and Chemical Engineering since the Second War have had dominant instrumentalist tendencies. In both fields there has been an impetus to generate equations for incorporating data with little or no conjecture about a "model" or "real world" lying behind the equations. Such equations are sometimes called "empirical equations" or, more pejoratively, "fudge equations." Data that might be inconsistent with the equations are generally handled in one of two ways: the equations are altered so that the data is incorporated, or "boundary conditions" are imposed that, in essence, simply proclaim the data not pertinent to an equation.

The instrumentalist view of knowledge popular in Physical Chemistry and Chemical Engineering has made both fields fertile for purely mathematical manipulation, with results that have not been entirely beneficial. Since teaching methods usually reflect views of knowledge, students are often encouraged by professors and by textbooks to become formula-pluggers, using empirical equations to plug in parameters when faced with a problem. While this technique seems practical for much work in both fields, it can seriously limit the student or practicing engineer or chemist when he is faced with an anomaly, or a totally new problem. Without adequate training in generating formulas from conjectures about a model of the real world, it is difficult to analyze the factors that lead to an anomaly. Literally, one does not know the meaning of the equation under question. When faced with an entirely new problem--one for which new formulas must be generated--the difficulties are overpowering for the same reasons.[8] There are also reasons why an instrumentalist

8. There are exceptions. Chemical Engineering Professor Stuart Churchill, in his recent textbook <u>The Interpretation and Use of Rate Data</u> (McGraw-Hill, 1974), forces students to formulate models of the real world and then generate their own equations from the models. James A. Bell was an editor of this book.

view of knowledge can be a serious impediment to theoretical progress, regardless of whether the view be held in Physical Chemistry, Chemical Engineering, Psychology, Economics, or any other science or social science. A discussion of those reasons appears in Section VII-B.

Although the following may be a rather bold conjecture about classical behaviourism in psychology, the view of knowledge held by its advocates is instrumentalism. Behaviourists concentrate on linking stimulus data with response data with a predisposition to use mathematical formulas to incorporate the observations. Equations are fudged and boundary conditions are set, along with a myriad of other ad hoc strategems, to ward off any data that might seem inconsistent with the equations. In short, classical behaviourism uses conventionalist method. The exclusion of all claims about the "black box,"--the real organism between the stimulus and response,--is nothing but positivism taken over in psychology.[9]

Ironically, instrumentalism is not as vogue amongst sub-atomic physicists as once was the case. The resistance of such physicists as Einstein, and its barrenness for theoretical progress, have perhaps been responsible. The cults endorsing instrumentalism are far from dead, however, and many practicing econometricians are not exempt.

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9. Many in psychology who call themselves behaviourists are not classical behaviourists, of course. Those, for example, who call themselves S-O-R (stimulus-organism-response) behaviourists are interested in finding explanations of changes within the organism.

VI. PARADIGMISM REINVENTED: THOMAS KUHN'S VIEW OF KNOWLEDGE

> "Physical concepts are free creations of the human mind, and are not, however it may seem, uniquely determined by the external world." (Einstein, Evolution of Physics, 1938)

The influence of Thomas Kuhn's view of knowledge on system dynamics can hardly be overemphasized. The adoption of his most crucial word--paradigm--into the system dynamics lexicon is indicative of its significance. Familiarity with two interpretations of Kuhn's ideas, and the arguments against one of those interpretations, are important for those working in system dynamics.

A. Whewell Revisited

Most of Kuhn's methodological theses parallel those of Whewell. They are the following:

(1) that science grows by imaginative new ideas which are then used to search out facts.

(2) that facts are only seen in light of these ideas; research is directed to uncover the facts.

(3) that scientists try to colligate ideas into a unit.

(4) that there is a strong tendency to force the world to fit one's ideas.

(5) that rough comparisons of the legitimacy of competing ideas can be made by measuring them against nature; the comparison often leads to the separation of mistaken ideas from other ideas in a unit.

Unlike probabilism, these five theses were not compatible with inductivism: they offered no possibility for a compromise that would retain an inductivist core. While the heros of probabilism were acclaimed--Thomas Bayes was selected for membership in the Royal Society--Whewell remained an outsider.

B. Kuhn and The Structure of Scientific Revolutions

The Introduction to Thomas Kuhn's The Structure of Scientific Revolutions (second edition, 1962) begins with a criticism of inductivist interpretations of the history of science, and then outlines the most important theses in the book. Whewell is not mentioned among those whose ideas were germinal for Kuhn's book, nor is Whewell cited by Kuhn as an inspiration for any other of his papers or books as far as we know. In any case, Kuhn's development of paradigmism closely follows the first four of William Whewell's theses. The fifth Whewellian thesis, however, sometimes surfaces in Kuhn's work but at other times is deliberately drowned. The spasmodic affirmation and denial of the fifth thesis has led to considerable confusion, with consequences important for system dynamics. Let us now see the details.

A given view of the world along with methodological beliefs, epistemological assumptions, and other background assumptions seem to constitute what Kuhn calls a "paradigm." Quoted below are a few passages among the many which describe a paradigm:

> Close historical investigation of a given specialty at a given time discloses a set of recurrent and quasi-standard illustrations of various theories in their conceptual, observational, and instrumental applications. These are the community's paradigms....Paradigms may be prior to, more binding, and more complete than any set of rules for research that could be unequivocally abstracted from them....(Paradigms) are the source of the methods, problem-field, and standards of solution accepted by any mature scientific community at any time....[10]

10. Kuhn, 1962 pp. 43- and parts from a quotation from Kuhn in "Major Modelling Paradigms," Donella Meadows, P.4 of First Draft of The System Dynamics Method, 1976.

One cannot help but notice a certain vagueness in the paradigm descriptions. At times a paradigm seems inclusive of methodological theories and epistemological theories, sometimes a paradigm seems constituted entirely of them, and at even other times paradigms seem to be grouped under methodological and epistemological theories without including them. The vagueness obviously hinders ones understanding of Kuhn's most important concept.

In any case, paradigms provide the basis for a research program, and "normal science" is that part of science devoted to working out the research program of a paradigm. Paradigms, and the normal science extending from them, operate according to the first four theses of Whewell. The fifth thesis of Whewell, however, Kuhn sometimes endorses:

(1) A paradigm is thrown into doubt when an accumulating number of facts do not justify it.

(2) A new paradigm would have to explain crucial facts that are anomalies in the old paradigm.

(3) A new paradigm explains facts about which its predecessor implies nothing.

And sometimes denies:

(1) No paradigm can ever be reduced to another--mathematical formulations adhering to paradigms cannot even be reduced one to another.

(2) Adoption of one paradigm over another is ultimately a leap of faith.

(3) Acceptance of a new paradigm is an emotional experience, not an intellectual transition.

(4) Paradigms spread, and are accepted, because of sociological reasons--the fame of its author or supporter, the popularity of a textbook expousing it, etc.

In short, Kuhn offers two conflicting theses: we can compare and select paradigms by intellectual criteria, and we cannot. Kuhn seems to emphasize the second thesis, however. Why?

One suggestion is that Kuhn was fascinated with the parallels between scientific revolutions and religious conversions, concluding that the two were similar. Another suggestion is that Kuhn was so impressed by the similarity between Gestalt switches--the psychological tendency to delineate entirely different patterns in a identical field--and changes in views of the world that he superimposed the former concept onto the latter. Since the two sides of a Gestalt switch seem incompatible, Kuhn might have concluded that paradigms are incompatible.

There is still another explanation, one that can be clarified by outlining an argument responsible for Kuhn's second opinion:

Premises: (A) Reasoning assumes basic ideas.

(B) Basic ideas--a paradigm--cannot be criticized effectively by people who use those same ideas to reason.

Conclusions: (1) Criticism can only be made effectively by stepping outside a paradigm.

(2) Revolutions in science--which require changes in basic ideas--are made only by adopting a paradigm outside the given one.

The first premise in this argument seems unavoidably true. Even a hard-core inductivist would have to admit that, in order to search for "facts," the researcher must presuppose certain ideas about that for which he is searching.

The second premise, however, is mistaken. We are often able to criticize basic ideas with which we ourselves reason. The history of science provides

examples of scientists who were able to criticize the basic ideas within which they worked. Two of the most obvious were discussed earlier: Newton questioned his own theory of gravitation even though it was crucial to his dynamics and celestial mechanics; Einstein distrusted a probabilistic interpretation of quantum phenomena even though his formulation of a probabilistic interpretation formed one essential foundation of quantum mechanics. In neither case was there a shift to another paradigm in order to make the criticism. No new view of the world was invoked unless, of course, the notion of paradigm is defined so loosely that any criticism must entail a change of paradigm.

Criticism of basic ideas is not, of course, restricted to the physical and mathematical sciences. Some monetarist economists are beginning to find mistakes in their own thesis that the supply of money is the key to controlling inflation and recession. Some behaviourist psychologists are pointing out the inadequacy of their own explanations of human creativity. A group of specialists in system dynamics studies and criticizes its own modeling assumptions and techniques. In short, basic ideas not only can be, but also are criticized by those assuming them. The greatest hinderance is believing it cannot be done.

Despite much evidence to the contrary, many intellectuals persist in believing that they cannot criticize their own basic ideas. There are at least two major explanations for this dangerous misconception. The first is an uncritical acceptance of sociological explanations for intellectual ideas: the belief that a person's ideas are reducible to sociological forces--his family, his friends, his work, his economic class, etc. Since one has no substantial control over membership in such groups, the explanation maintains, and since one's basic ideas are the result of membership in such groups, it follows that one has no control over one's basic ideas. Indeed, many of our ideas are formed in the context of sociological forces; but those ideas can be and often are broken by people. The second explanation: from the fact that basic ideas are often held dogmatically, it is concluded that basic ideas are inevitably held dogmatically. This fallacious extrapolation is unfortunately very prevalent.

The conclusion that effective criticism can only be made by stepping outside a paradigm makes sense only because it is mistakenly believed that effective criticism cannot come from within the paradigm. Now, effective criticism can and often does come from those holding different basic ideas from one's own. The perspective gained from an alternative paradigm can provide the insight that reveals flaws in one's own ideas. In sum, effective criticism of basic ideas can come from all types of sources, both from within a paradigm and from outside a paradigm.

The conclusion that revolutions, which require changes in basic ideas, occur only in the presence of a new paradigm is a corollary of the conclusion above and is therefore subject to the same comments. Change in science often occurs by adoption of a new paradigm outside the given paradigm, but it also results from criticism within a paradigm. The changes that resulted from criticism by Newton and Einstein of their own basic ideas provide examples.

VII. PROBABILISM, INSTRUMENTALISM, PARADIGMISM: PROS AND CONS

> "The advance of science is not comparable to the change in a city, where old edifices are pitilessly torn down to give place to new, but to the continuous evolution of zoologic types which develop ceaselessly..." (Henri Poincare [an instrumentalist], Valeur de la Science, 1904)

The historical analysis of views of knowledge has clearly shown that they can be an aid or hinderance to the development of science. Although the epistemological and methodological elements in a view of knowledge are closely related, the methodological theories of importance for this essay all had one common epistemological root: the realization that knowledge is not Truth. The arguments for and against probabilism, instrumentalism, and paradigmism are thus due primarily to differences in their methodological elements.

We have also seen that, like tools, methodological theories should be designed and fashioned for the task at hand. They should be formulated to deliver the type of knowledge we seek, even though they sometimes deliver surprises. It would be just as ridiculous to apply one methodology blindly in all situations as it would be to use a screwdriver to drive a nail, to gouge wood, or to use it for other purposes inconsistent with its design. Methodological theories are as indispensable as carpentry tools, but just as subject to inherent design limitations.

A. Desiderata for Weighing Views of Knowledge

What criteria ought be used to decide the relative merits of views of knowledge? The following three criteria seem appropriate:

(1) Problem-solving power. The types of problem for which a view of knowledge can generate fruitful solutions should be considréd. The importance of those problems should be weighed, despite the value-judgments that will inevitably be involved. The range of problems for which a view of knowledge is useful should also be taken into account.

Another paper in this same volume, "The Unavoidable A Priori" by Donella Meadows, is largely devoted to comparing the problem-solving power of system dynamics and its alternatives. In this essay, then, we will focus on the next criterion.

(2) Theoretical progressivity. A more subtle but extremely important consideration when weighing views of knowledge is the impetus and/or constraints entailed for theoretical progress. Any view of knowledge will render formulas for generating and legitimating knowledge--that we know. What is desired, however, are views of knowledge which will generate and legitimate ideas that are likely to lead to new--often unforeseen--insights. New insights can result in new problems for solution, and/or new solutions to old problems.

It is often forgotten that generation of new insights requires that our view of knowledge encourages the generation of ideas clear enough that they are vulnerable to error. Ideas that are vulnerable to error can be fruitfully criticized and hence improvement can be made. New insights are seldom if ever the result of views of knowledge which encourage concealment of error, whether by toleration of vagueness, by allowing ad hoc strategems to explain error away, or by discouraging the criticism necessary to uncover error.

(3) Other fallout. This category is a collecting point for all other consequences of holding a given view of knowledge. In addition to the role played by views of knowledge in suspicion of other ideas and propogation of one's own ideas, they can be influential in the formation of social-political structures and personal attitudes. To take one example: if a view of knowledge entails that knowledge is Truth and that Truth can be obtained by avoiding error, the pressure to be "right" and to avoid error at all cost can encourage dogmatic and defensive tendencies that might be significant in the functioning--or disfunctioning--of a liberal democracy. Leaders might be encouraged to think they know what is best for everyone (the Truth), and citizens might not be inclined to execute their important role as critics of public policy. Discussion of the many consequences that views of knowledge can have on our

social, political, and personal lives would fill many books, and the discussion has hardly begun.[11] It is with regret that the authors, due to space limitations, will limit discussion to a few significant consequences of paradigmism, the most popular view of knowledge in system dynamics.

B. Probabilism and Instrumentalism in Econometrics

Perhaps the greatest advantage of probabilism and instrumentalism for theoretical progress is the encouragement to search for corrolations without being constrained to offer explanations for the correlations. Some correlations might lead to further correlations that were unforeseen. Looked at from another perspective, if one feels obliged to explain data in terms of a real-world model, data corrolations which do not fit the model might be avoided. For example, an instrumentalist econometrician attempting to find correlations that constitute indicators of a future slowdown in capital investment could make correlation runs with all sorts of data, and some correlation(s) might become evident that had not even been considered. A non-instrumentalist, on the other hand, might already be committed to certain types of correlations that he infers from his model of reality, such as money supply. The prior commitment might constrain the search for correlations that are not explained by money supply. New insights might not be realized.

11. James A. Bell is presently working on a manuscript, "Inductivism in American Life," which attempts to trace the many influences of inductivism on American attitudes and habits. Business organizations, school systems, political traditions are a few of the institutions deeply affected.

Now, instrumentalists in econometrics are inevitably committed to use of probabilistic techniques. The reason is that the data they use is the result of so many human influences that perfect --non-probabilistic --correlations are practically impossible. Unlike the physical sciences, precisely repeatable phenomena are not possible. They are, then, forced to select data, which amounts to deciding on constituent factors, and stochastic calculations--whether actually done or only tacitly assumed--cannot avoid consideration of prior probabilities. Instrumentalist econometricians are, in other words, faced with the same two difficulties faced by the handicapper trying to calculate the probability that Prancing Prince would win the Kentucky Derby. Instead of data from a daily racing sheet--which includes names of trainers, weights, previous race results, etc.--the instrumentalist econometrician has data on previous public investment trends, private investment trends, Eurodollar fluctuations, etc.

There is one tremendous impediment to theoretical progress by those using instrumentalist and/or probabilistic views, however, whether they be in econometrics, psychology, chemistry, engineering or any other field. <u>Instrumentalist and probabilistic views greatly lessen vulnerability to error</u>. The argument for this claim, mentioned in passing in Section VII-A-(2), is complicated but clear. The condensed version below contains the major highlights of the argument.

Instrumentalist correlations are less vulnerable to error because, by making no commitment to a model of the real world to explain correlations, there is no deduction of possible data that, if found, could falsify a model. Looked at in another way, instrumentalist correlations are of data that correlates and <u>not</u> of data that does not correlate. Data which does not correlate is excluded by boundary conditions, or "fudged" into the equation by

mathematical manipulation, or simply explained as one of those improbable--but possible--exceptions. If errors are not found, the chance for breakthroughs via new models of the real world is lost because the errors in a previous model enable us to know what weaknesses must be overcome by a better model. Now, new models might be revolutionary, or they might not, but they often lead to insights that might otherwise never have been recognized.

We will now get a little more mileage from a previous example. Monetarists make models from which it is deduced that money supply--money aggregates, to be more precise--controls price inflation. But money supply has not controlled inflation as well as expected during the past few years, leading many monetarists to believe their model is somehow mistaken. The search is on for modified models--and it is likely that there eventually will be one or more models which are vast improvements. There might also appear a revolutionary breakthrough, a new model which offers a totally novel and fruitful range of insights. The chances for any breakthroughs, minor or revolutionary, are extremely remote for those using instrumentalist views in economics.

C. Paradigmism in System Dynamics

The outstanding advantage of paradigmism for theoretical progress is that it encourages the formulation of real-world models. The basic argument was outlined in the previous subsection, but let us now explore in more detail how formulation of real-world models in system dynamics leads to theoretical progress.

In system dynamics, attempts to formulate real models of the world lead to theoretical progress in two different ways. First, there is progress in modeling specific problems and second, there is progress in developing techniques to find and identify error in models.

When confronted with a specific problem for which a model is to be developed, a system dynamicist will often conject a model that is more or less crude. Regardless of how crude the model, however, certain expectations can be deduced from it which, when tested, might be found mistaken. The modeler can then run further tests to identify the error(s). New models can then be conjected--models which will hopefully overcome the error(s)--and so the process continues. The actual techniques used by system dynamicists to test for and identify error are many--endogenation of variables, exogenation of variables, sensitivity testing, robustness testing, use of top-down analysis, etc. The rationale for all testing, however, is to find and identify error in the model, because errors found in models can lead to formulation of better models. If models of the real world were not conjected, on the other hand, techniques to find and identify error would be greatly weakened if not eliminated entirely.

Theoretical progress in the development of techniques to find errors in models is also very important for system dynamics. This type of progress can be made because specific models, which vary greatly, sometimes lend themselves to a new technique of finding error or a better variation of an old technique to find error. The new technique or variation of an old technique is then sometimes found applicable to models for which it had never been used. The result is better techniques of exposing and identifying error, which leads to greater efficiency in developing models for specific problems. At this point there seems to be no foreseeable end to the improvement.

Incidentally, the authors know of no other field with such a direct relationship between practical application and theoretical progress. The reason seems to be that the techniques used to work on practical problems are themselves constantly and necessarily being redesigned and improved by

the very process of working on practical problems.

Now, the ideas above concerning two types of theoretical progress seem rather trivial because they are so fundamental to system dynamics, but it is very important that system dynamicists understand clearly why their commitment to making models of the real world is crucial. It is also helpful to know why such progress cannot be realized by those trapped by probabilism or instrumentalism.

Although paradigmism offers significant advantages for theoretical progress in system dynamics, the confusion of the two interpretations of Kuhn's paradigmism might inadvertently lead some people in system dynamics to adopt the second interpretation, i.e., the first four theses of Whewell with a denial of the fifth thesis. The consequences are not desirable. Let us see why.

Suppose we carry the second interpretation of Kuhn one step further:

(3) People outside a paradigm do not share the same basic ideas as those within, so their criticism cannot be relevant.

This conclusion follows because if both conclusions (1) and (2) from the second interpretation are true, rational discussion can only take place amongst people sharing the same paradigm. Combine conclusion (1)--effective criticism can only be made by stepping outside a paradigm--with (3), and the following conclusion cannot be avoided: the only effective criticism of a paradigm must come from outside the paradigm but criticism from outside the paradigm cannot be effective. In short, there is no effective criticism of a paradigm, either from within or from without.

The dogmatism and elitism in such a position are inescapable. It is dogmatic by maintaining that there are no effective criticisms of one's basic ideas. It is elitist by implying that only the initiated are qualified to judge a paradigm--and that judgment is guaranteed favorable because there is no effective criticism! What are the possible effects of this line of thought?

First, the advantages of paradigmism for theoretical progress might be seriously compromised. Models of the Real World--if held dogmatically the words should be capitalized--would hardly be explored for error. Even if error were found, the models would not be easily given up. Furthermore, serious consideration of other models of the real world would not be encouraged. In short, the tremendous advantages of paradigmism for theoretical progress might be neutralized.

Second, there could be difficulties in propogating ideas in system dynamics. There would be justification for preaching system dynamics rather than encouragement of others to adopt system dynamics by persuasion. Preaching can also be worthwhile in certain contexts, but it is no substitute for persuasion. It might also be believed that others, even ourselves, must adopt the entire system dynamics paradigm rather than accept, even with caution, some of its basic tenets. We would be either "in" or "out" of the paradigm with no middle ground allowed. Finally, system dynamicists might be content as an elite group, accepting only those who espouse their "faith." Some possibilities for professional and personal growth would suffer in such an atmosphere.

No one in system dynamics should actually desire any of the above consequences. But if one knowingly or unknowingly adopts the second interpretation of Kuhn's paradigmism, one might not only accept, but actually endorse these consequences as an inevitable product of being "scientific."

VIII. REFUTATIONISM: KNOWLEDGE AS CONJECTURES AND REFUTATIONS

> "The Gods did not reveal, from the beginning, all things to us; but in the course of time, through seeking, men find that which is the better.
>
> But as for certain truth, no man has known it, nor will he know it; neither of the gods, nor yet of all the things of which I speak. And even if by chance he were to utter the final truth, he would himself not know it; for all is but a woven web of guesses." (Xenophanes, 570-475 B.C., Verses, from Popper, 1963, page 26)

There already is a highly developed view of knowledge that is being used by system dynamicists. This view of knowledge--refutationism--has been expounded and improved over the past half-century by Sir Karl Popper and his followers. In a nutshell, the view is as follows:

Knowledge consists of conjectures about the real world, conjectures from which expectations can be deduced for empirical testing. The crucial quality of scientific conjectures is that they be refutable; that is, vulnerable to empirical falsification. If the conjectures pass empirical tests, they are corroborated; if not, they are falsified. In either case, progress is made. Corroborated theories are closer to (empirical) truth because they have survived certain refutation possibilities of the real world. Falsified theories can lead us closer to the truth because more progressive theories will be empirically corroborated where the falsified theories were refuted. The conjectures of science are thus not Truth, but they can lead us toward the Truth.

Refutationism preserves the benefits of paradigmism by stressing the importance of real-world models. Even better, it emphasizes the most important factor in improving our real-world models: the search for error. Refutationism also eliminates the deleterious consequences of paradigmism resulting from the most popular interpretation of Kuhn's work. Recognition that criticism leading to the exposure of error can emanate from those holding certain basic ideas or from those not holding certain basic ideas counteracts the dogmatic and elitist tendencies that can compromise theoretical progress, hinder the propogation of system dynamics ideas, and encourage a cultish rather than an open atmosphere.

Now, a number of arguments in Sections VI and VII of this essay have been indirectly inspired by the ideas of Popper. They have provided an introductory baptism into refutationism, whether the reader was aware of it or not. The authors would like to conclude by encouraging system dynamicists and others interested in the field to sharpen further their understanding of refutationism, the view of knowledge that system dynamicists should now be ready to adopt consciously. The books of essays listed under Popper's name in the bibliography are highly recommended as a starter.

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