SCIENCE AND ENGINEERING IN THE AGE OF SYSTEMS

by

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I - **A Note on Historical Ages**

"The attitude to scientific knowledge defines the value system of a society" and when that value system creates a dominant image of the world, we may be permitted to talk in terms of an age.

Daniel Bell writes of the medieval conception of natural science as that of forbidden knowledge. "The divines feared that 'knowledge puffeth up' and that it 'hath somewhat of the serpent'. During the Christian centuries, 'nature,' in quite a special sense, had been consigned to the satanic order. The Faustus legend used by Marlowe testified to the fascinated dread of natural science for the Middle Ages" (1). Thus, the dominant worldview of Western societies was one of preoccupation with death and the supernatural (2).

MACHINE AGE - By the turn of the seventeenth century the Western world had already been through the Crusades and on the way had learned about the ancient worlds of Greek and Rome through association with Islamic scholars. Renaissance was blooming. The belief in man's expansive power had begun to replace the earlier vision of fear. "In Francis Bacon's New Atlantis, which he intended to replace the mythical Atlantis of Plato's Timaeus, 'The King', is no longer the philosopher but the research scientist. And on the frangible island of Bensalem, the most important building, Solomon's House, is not a church but a research institute." It is important to note that the image is one of searching. Searching, of course, would be pointless unless it was believed that what was searched for could be found. This is the corollary to saying that the Western world began to think of nature in terms of understandability and control, and at the dawn of the industrial revolution the hope for ultimate understanding was high. "The end of our foundation is the knowledge of causes, and secret motion of things; and the enlarging of the bounds of human empire, to the affecting of all things possible"(3), says one of the "Fathers" of Solomon's House.

Francis Bacon; that "...wisest and meanest of mankind," according to Pope; in fact was ushering in, the Machine Age, by guiding the minds of generations of Europeans toward the search for the "knowledge of causes." Cause and effect became the shared view that dominates the Western world. The cause C is both necessary and sufficient for effect E. If I understand C, I will understand all there is to be understood about E. Given enough time and intelligence, man could understand all C's of all E's and all C's of those C's, till he/she would at last arrive at the lofty mountain top of omniscience, where he/she would know all that is to be known.

Rene Descartes provided the tool for that adventurous mountain climbing when he set up his four rules of "searching for the true methods of arriving at the knowledge of everything"; among which he proposed "to divide each of the difficulties" he was examining into "as many parts as possible and as is required to solve the best "(4). This - the method of analysis - captured the mind and intellect of man and created the instrument by which science became the dominant path in the search for "truth" by Western educated man. Generation after generation of "thinkers" became convinced that the undeceiving and revealing <u>nature</u> would submit itself to search and unfold its secrets, however gradually and reluctantly, but comprehensively.

According to Ackoff, analysis is a three-step operation: 1) to break the "thing" you want to understand into its parts; 2) try to understand the parts, and 3) aggregate the understanding of parts to attain the understanding of the "thing" itself (2). It follows that if we believe we would ultimately understand all that there is to be understood, the process of analysis should in the end discover, the indivisible "thing." It was time to journey backward to rediscover the "atom" of Democritus, "cells" of biologists, and forward to define "single ideas" of Locke; "id," "ego" and "super-ego" of Freud. All in all, science became preoccupied with the quest for understanding the indivisible parts. And wow! What a success!

Analysis helped man to conquer the oceans and mountains, forests and animals, hunger and sickness, atoms and heavens, so much so, that we accepted uncritically the awesome assumptions that underlay our machine age concept of the world. We bought, wholesale; the Newtonian notion imposed on our minds that the world is a hermetically sealed machine. "In this machine we are just cogs, levers, and wheels and our hopes, dreams, aspirations, thoughts and actions are all pre-determined" (5).

The basic characteristics of the machine age according to Prigogine were the notions of lawfulness, determinism and reversibility and no place do they reign more supreme than in the most exalted womb of science: dynamic. Here, all that we have to know are the laws of motion and an empirical definition of a single instantaneous state of the system. Knowing these permits us to know all the future and all the past period. Nothing else is needed (6).

The 18th century mathematician Laplace put it this way: "an intelligence knowing all the forces acting in nature at a given instant, as well as the momentary position of all things in the universe, would be able to comprehend in one single formula the motion of the largest bodies as well as the lightest atoms. To it nothing would be uncertain, the future as well as past would be present to its eyes "(7).

SYSTEMS AGE - Not so, declared unintentionally, the 1931 Noble Laureate Physicist Werner Heisenberg in a sweeping principle that shook the structure of-determinism and consequently the whole machine age image. Heisenberg developed his principle of uncertainty in 1927 after realizing the hopelessness of physicist's efforts on the mathematical representation of the electron path in the cloud chamber. I began, wrote Heisenberg, "to wonder whether we might not have been asking the wrong sort of question all along. But where had we gone wrong? ...It must have been one evening after midnight when I suddenly remembered my conversation with Einstein and particularly his statement: 'it is the theory, which decides what we can observe'. I immediately convinced that the key to the gate that had been closed for so long must be sought right here...we had always said so glibly that the path of the electron in the cloud chamber could be observed. But perhaps what we really observed was something much less. …The right question should therefore be: Can quantum mechanics represent the fact that an electron finds itself approximately in a given place as it moves approximately with a given velocity, and can we make these approximations so close that they do not cause experimental difficulties? …A brief calculation showed that one could indeed represent such situations mathematically, and that the approximations are governed by what would later be called the uncertainty principle of quantum mechanics: the product of uncertainties in measured values of the position and momentum (i.e.. the product of mass and velocity) cannot be smaller than Planck's constant[1]. This formulation, I felt, established the much-needed bridge between the cloud chamber observations and the mathematics of quantum mechanics"(8).

In non-physicist's language the uncertainty principle, unceremoniously, metamorphosed the notion of "cause-effect" and it instructed man to give up on the notion of complete understandability and find ways to live with the ambiguity. The journey toward the ultimate scientific truth that man so valiantly embarked on, when on that fateful day on April 28, 1686, Newton presented his Principia to the Royal Society of London took a new direction. John Dewey, a son of the New World, took up the challenge and in his book, Quest for Certainty, argued that the complete understanding is an ideal - something to be approximated ever closer but never achieved (9).

In a world where complete understanding becomes elusive there is no certainty that objects, states, processes, and relationships ultimately break down to simple and indivisible parts, as analysis assumed. We may have to deal with "things" that can structurally be broken into parts but would lose their function and their essential properties in doing so (2). Ludwig von Berthalanffy named such "things" system (10).

A system, according to Russell Ackoff, is a set of two or more interrelated elements of any kind: concepts (such as number systems), objects (such as a body or a telephone), people (such as a social system) or a combination thereof. Ackoff's definition of a system is quite comprehensive and is as follows (2): "The elements of the set and the set of elements that form a system have the following properties:

- Each element has an effect on the set, much as the organs of an animal influence the properties of being an animal.

[1] It is interesting to note that Einstein steadfastly refused to accept the principle of uncertainty when he first discussed it at Solvay Congress in Brussels and tried to think of cases in which the principle would not hold. "God does not throw dice", was a phrase he was heard to say (8).

- Each element is affected at least by one other element in the set, such as the brain in the body depends on the function of the lung.

- Every possible subgroups of elements have the first two properties."

This definition implies that a system has emergent properties that will be lost if and when the system is broken into its parts. The whole cannot be decomposed to subsets without losing its essential properties. "A system is more than the sum of its parts." Viewed structurally, a system is a divisible whole, but viewed functionally it is an indivisible one and has two critical properties (2):

1. "Emergent property is lost when the system is broken - life cannot exist in severed organs, and;

2. When a part is taken out of the set that part will lose its essential properties - a hand cannot write if it is not attached to the body."

It is the system concept, Ackoff argues so convincingly, that presents the Machine Age with its final dilemma: if the essential and emergent properties of a system is lost when that system is broken into its parts, how can analysis, a process that requires such a breakdown, claim to understand the emergent properties (2)? If we are interested in understanding something about "life," that emergent property which only exhibits itself when organs of an animal work together in miraculous and awesome interrelationships, how can analysis, the process that requires breaking down, find answers? No! says Ackoff - on behalf of a generation of thinkers in many different fields who were frustrated by the impotency of machine age explanation - analysis is insufficient!

Ackoff argues for synthetic thinking, in addition to and not as a substitute for analysis. Synthetic thinking requires that 1) a "thing" to be understood should be embedded in a containing whole, 2) the behavior of the containing whole should be explained, and 3) that explanation should be desegregated to understanding of the "thing" itself. This is the ideology of "expansionism" as opposed to reductionism.[2] The answer to "why" of things is never contained in the "thing" itself but must be found outside that "thing." Analysis, says Ackoff, provides data - the answers to "what, when, where, who, whom, which, how many, whose"; and knowledge - the answer to "how to."[3] Synthetic thinking provides answers to "why." Can anyone explain why, asks Ackoff, a six passenger car became the normal size of the car in the U.S. by breaking the car into its components? The answer is of course no, but it may be found in the context of the societal system which contains the car as a sub-system. Early in the development of the car the average family size in US was about six (2,ll).

[2] In the following sections we will refer to the process involved in expansionism as "embedding", for reasons that will become obvious later.

[3]The word knowledge is used in two different senses: as a declarative statement which descibes things as they seem to be, and as word of empowerment when it is a respone to the question of how to.

Reductionism, as stated earlier, is structurally the concept of ultimately indivisible parts and functionally is the concept of cause and effect relationships resulting in the doctrine of determinism. But what would the implication of expansionism be? The answer was given years ago by Edgar Arthur Singer, Jr., a civil engineer as a youth and later a Professor of Philosophy at the University of Pennsylvania. Singer said that when something C is the cause of something E then that something C is both necessary and sufficient to cause E, but in most real situations C alone cannot cause E, because C, although necessary for E, may not be, and normally is not sufficient for it. He reexamined the famous example of "acorn-oak" relationships and said although the acorn is necessary for the production of oak, it is not sufficient. Thus acorn alone cannot produce oak unless there exists many other necessary elements such as good soil, water, sun, etc. No! said Singer, acorn is not the cause of oak, it is its "producer." He developed the idea of producer-product as a richer substitute for the notion of cause-effect. For a producer to produce a product there must be co-producers. A producer and its co-producers are jointly the cause of the oak, not the cause alone (12).

The implications of the producer-product concept are enormous. While the cause and effect relationship assumes a closed system, i.e., a system that does not have any environment, the notion of producer-product envisions an open system, i.e., a system that co-producers (environment) are as important as the producer itself in creating an outcome. Only when the whole universe is taken as a system of interest, producer-product and cause-effect become identical. But only "God" is privileged to deal with such a system. The rest of us, as important as we may think we are, have to live within the world of producer-product, and of necessity deal with the environment as a co-producer of all our thoughts, feelings, behaviors; and all events, processes, and objects surrounding us. Expansionism is a process by which the influence of the co-producers (environment) can be swept into consideration.

What is really involved is the recognition that because of the "environment" the "real thing" can be viewed from different perspectives with a different but yet "truthful" view of reality. Singer offers a pictorial example to illustrate the point. Ackoff tells it this way: if a traveler from another planet who has not seen an orange before, enters the room, and pointing to an orange and asks you "what is this?", the answer, of course, is that it is an orange. Then, if he further asks "what is the orange for?", the answer may be: "let me show you," meantime slicing the orange into two pieces to let him taste it. The half orange may look like Figure la. Suppose at this time a friend enters the room and learning about your conversation suggests that you really should have sliced the orange in the opposite direction because it is easier to eat, proceeding to slice another orange to make his point. His half of the orange may look like Figure lb. Which of these two representations: Figure la or Figure lb, do represent the reality? It is obvious that both represent the reality, i.e., they are true: the same objects viewed two different ways (11).

Fig

Singer said that our mistake is to think that the world can be sliced only in one way. Viewed in the context of producer-product concept, choice and free will become aspects of reality quite consistent with cause and effect (12). Niels Bohr's theory of complementarily which he developed in 1927 to describe a situation in which it is possible to grasp one and the same event by two distinct modes of mutually exclusive, but complementary interpretation is a more rigorous version of the same philosophical idea (13). Briefly then, the mechanistic worldview takes it for granted that man would eventually become privy to the creator and would discover the mystery of the universe. We would accomplish this amazing task by the use of "analysis" to search for "truth," and the only truth, in a closed system. Further, the behavior is explained by what caused it (2).

The system worldview denies all of the above premises. It denies that the world is completely and unambiguously knowable; it denies that "analysis" alone without the help of synthetic thinking (embedding) can explain the world; denies that cause and effect, not enriched by the concept of producer-product, is the only tool for slicing the world; denies that "real" can be described in only one scientific way; and finally asserts that choice and free will is completely compatible with the producer-product view and can be objectively studied.

I began this paper by quoting Daniel Bell as a prelude to justifying the naming of an historical age. The fact that in major respects, the concepts of the Machine Age differ from system thinking I hope by now, is obvious. Whether or not the transition has occurred to a significant degree to the point that system concepts are becoming a shared view of the Western societies is another matter and more difficult to say. Von Bertalanffy, a pioneer in systems thinking and many other students of the field feel this is so. Examples abound (2,10).

The choice of name for an age is, of course, problematical. You may call this the post-industrial age or the age of information or computers, etc. But it appears to me that the claim of many researchers who call this, the Age of Systems is as justifiable. I personally believe this is an Age of Systems and get my clue from no other authority than "Dick" of "Dick and Jane" fame. Generations of Americans grew up on the adventures of "Dick and Jane" and must agree that this is the system age when we are informed by the writer of the sequel to Fun with Dick and Jane that "Dick, now 48 years old, has grown up to become a system engineer working with a utility." What more evidence does one need to declare this the age of systems!

II - Science and Engineering

It is one of the ironies of our educational system that scientists and engineers, almost never, are exposed to the question of what it means to be a scientist or an engineer while in school. It is by the process of certification that one comes to believe that he/she is a scientist or an engineer and much later in life, by some process similar to osmosis, does one come to feel, to have become a scientist or an engineer. We were happy to believe that science was the search for the truth and engineering the art of applying sciences to serve mankind (or some variation) and that was the extent of it. We never recognized that although there may be one reality, "truth," as we perceive the reality to be, may be of several kinds; and scientific truth is only one of them. The notion of many truths (but one reality) is a bewildering experience for a scientist. It somehow offends his/her sense of lawfulness. "God does not throw dice."

Inquiring Systems - What do we mean by the elusive concept called truth? "It is obvious" writes van Gich, "that truth is a concept which can only be defined axiomatically, i.e., it is the presumed answer to a specific question which is posed according to pre-established rules" (l4). And those rules are a part of our justification of what we think the truth to be.

C. West Churchman has characterized the history of Western epistemology by introducing the concept of inquiring system (IS) and its classification according to several systems of thought (15). To Churchman, "inquiry is an activity which produces knowledge that makes a difference in and of itself. Knowledge is an ability, a potential, of some person to do something correctly. Inquiring systems embody the reasoning process and rules by which truth is found." Thus, we must know something about inquiring systems to be able to discern the real meaning of a scientific truth.[4]

Churchman identifies five scientific inquiring systems based on their assertion regarding the truth. These systems can be roughly classified according to the two important assumptions of each system. "The first assumption has to do with the degree of reliance on the method by which men gain knowledge through elementary-to-complex process. In one extreme of this scale, the system assumes that the mind begins by learning the simplest and clearest things first and then gradually progressing to learn about more complex matters by building up from these elementary forms of knowledge. On the other extreme of this scale it denies the existence of any simple clear things. In the latter system everything is complex. The second assumption has to do with the degree of control that the system has over its beginning. In one extreme of this second scale, it is assumed that the learning begins with input (sensory experience of outer world) i.e., beginnings are treated as a given, which the inquiry system cannot control. In the other extreme of this second scale the system denies existence of such givers, i.e., no inputs." Figure 2 shows that these two assumptions allow four pathways to learning.

Four classes of inquiring systems may be recognized: 1) those that begin with elementary inputs which are clear and distinct [Lockean]; 2) those that begin with clear and distinct ideas which are not inputs (i.e., not "given" externally) [Leibnizian]; 3) those that begin with complex inputs [Kantian]; or 4) those that begin with complex material which is not an input [Hegelian and Singerian] (l5). An important question regarding these inquiring systems is that how do the systems know their "beginnings" are true, i.e., who guarantees their content?.[5] Each system of inquiry deals with this question differently and the differences have profound implications regarding our understanding of science and technology.

Leibnizian inquiry does not begin with inputs that are externally given but with "innate ideas" where aspects of the symbol stream are under the control of the inquiry system. The truth is the end point of the process of inquiring and is concomitant with internal consistency, completeness and comprehensiveness. The truth is analytic. Who guarantees the truth of a Leibnizian system? "The precise specification of what shall count as a proof for a derived theorem or presupposition, " answer Mitroff and Turoff (16). In this inquiring system, all sentences are contingent. "A candidate sentence becomes a 'contingent truth' if it can be linked to some sentence in memory. Thus the memory becomes a 'fact net' by which the truth of a sentence is verified. Empirical data is considered only as contingent truth, inherently a

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[4] In this paper the word "truth" is used to mean what we learn by using various inquiring systems. Thus, while the reality may be one, the truths may be many.

[5] A historical note: The Cartesian Guarantor was God, Spinoza's Guarantor was human intuition.

risky base upon which to found universal conclusions (15). A great deal of practice of science can be viewed as a Leibnizian inquiry where theory governs the practice of scientists. In theory dominated sciences things are "objective if they fit the fact net; objectivity is based on linkability. Consequently, theoretical laws which imply a large portion of the "fact net," will be safeguarded by the scientific community with much zeal (l5). This is a part of normal science in Thomas Kuhn's sense (l7). Geometry, logic, etc are Leibnizian sciences.

The Lockean inquiring system differs from Leibnizian in its notion of its beginning. "Its truth content is associated entirely with external events, no theoretical construction is involved." The Lockean inquirer begins with a "blank tablet" and fills it up, as external data is received and matched with a list of basic properties called "simple sensations." The Lockean inquiring system asserts that truth is experiential (6). The objectivity rests upon the concept of other "observers." "If one asks a child, 'what color is this?' how does the child learn to respond correctly? Evidently, the correctness of the response is judged by adults and in general by a group of 'normal observers'. This is a Lockean 'community', having the same property tables, as well as the same labels for compounds (15). Things are "objective" if the community of experts, through free association agree. "Where in Leibnizian IS, the networks are theoretically, deductively obtained, in Lockean IS they are empirically, inductively derived (16). Who is the guarantor of the "truth" content of a Lockean inquiry system? The community of experts, answers Churchman, pointing out that an empirical generalization depends on plurality of inquirers and this plurality is a necessary condition for the verification of empirical truth, although it is not a sufficient condition (l5). A great deal of practice of empirical science is Lockean. Engineering Sciences are example of Lockean systems.

What a shocking experience for an engineer to learn that one's concept of reality, observation not withstanding, depends on other engineers' agreement and not that his/her observation is really real. "In the case of human inquirers [in the Lockean system], the arguments to establish the objectivity of data are based on strong subjective opinions about the characteristics of the inputs (15). In a nutshell it is erroneous to assume that observation is independent from the observer and the process of observing. This being so, how close do the inductive empirical sciences come to finding reality and perceiving the truth as they claim their mission to be? How do we engineers know what the truth is?

Leibnizian and Lockean systems being at a loggerhead (5) and denying each other's premises, made it natural for someone to try to synthesize both concepts into a new inquiring system. Kant attempted this. Will Durant puts it this way: "There is nothing in the intellect except what was first in the sense, says Locke. Nothing, except the intellect itself, replies Leibniz. It is our purpose, it is ourselves, our personalities, our minds, says Kant, that bring light upon these senses. No, there is a lawgiver for this mob [sensation], a directing and coordinating power, that does not merely receive, but takes these atoms of sensation and molds them into sense"(7). Kant proposed that the truth is associated with both the system's formal content and its empirical inputs. In the Kantian inquiring system, according to Churchman, what is received is a pure sensuous intuition that is shaped by the forms of space and time-and made intelligible by the categories (15).

The synthetic aspect of Kantian inquiring system becomes evident when we contrast it with both the Leibnizian and the Lockean systems. In Leibnizian inquiring system many possible different "fact nets" can be constructed but Leibniz thought that because God had ordained it so, they of necessity will converge. In the Kantian inquiring system, like Lockean inquiring system, experience provides a foundation for constructing, in Leibnizian senses a meaningful "fact net." Thus the experience must be sifted and integrated according to a theoretical construct for it to reach the level of objectivity. Objectivity in Kant's system cannot exist without the subjective molding of some kind of theory. Any non-trivial observation must be based on an a priori decision about what should be observed (15). When a scientist designs an experiment he/she concentrates on a very limited number of parameters. Why? How, for example, does he/she know that the color is not an important parameter in a falling body experiment, if there is no a priori theory? In a Kantian inquiring system, many theories and observations are admissible and many objective worlds may be constructed. The guarantor of such a system, say Mitroff and Turoff, is the degree of the fit or match between observation and the prediction of the theory. In a Kantian inquiring system the truth is synthetic (16).

Kant would allow a multitude of models of the world; Hegel, only two. In a Hegelian inquiring system: "Every idea is a group of relations; we can think of something only by relating it to something else, and perceiving its similarities and its differences. An idea without relations of any kind is empty. Every idea and every situation in the world leads irresistibly to its opposite, and they unite until they form a higher or more complex whole." Hegel agrees with both Shelling that there is an underlying "identity of opposites" and Fichte that thesis, antithesis, and synthesis constitute the formula and secret of all development and reality (7). In the Hegelian inquiring system the objectivity is the end product of the process of the dialectical debate between two opposing world views and the emergence of a synthesis. Why should the process lead anywhere at all? As Churchman puts it, it may be a dream - a dream that the conflict becomes a process by which objectivity will emerge. The Hegelian inquiring system asserts that truth is conflectual (16).

The Singerian-Churchman inquiring system is both an easy and a very difficult concept to unfold. It is easy to grasp the basic idea because it assumes that the truth is relative to the overall goals and objectives of inquiry. But this should not imply that it is based on the notion that "everything" goes (16). Perhaps it would be more accurate to say, with Mitroff and Turoff, that the Singerian inquiring system is a management theory for applying other inquiring systems. The image of the Singerian system is teleological (16). In Singerian inquiring system no element has priority over any other. The system should be viewed holistically and in the tradition of expansionism.

Describing this process as "sweeping-in," Churchman writes: "Singer's method follows a traditional one of starting with logic and noting the dimensions added by each science in turn. Thus arithmetic adds number and numerical laws; geometry adds points, line, plane, etc., and the laws of space; kinematics adds time and pure kinematical laws; mechanics adds maps and mechanical laws; physics adds group and fields and statistical laws ("randomness"); biology adds function, organism and purpose, and teleological laws; psychology adds mind and psychic laws; sociology adds groups of minds and group laws; ethics adds ultimate purpose and moral laws"(15). In doing so, the Singerian inquirer becomes now and then a Leibnizian, a Lockean, a Kantian and a Hegelian inquirer.

A novice may say: After all, hierarchical taxonomy of sciences from elementary concepts of particles to the complex of life is an old game - what is new here? The answer is a subtle one: there is no hierarchy! Understanding of particles hinges on the behavior of the observer. To understand the behavior of an observer one has to understand psychology. Understanding the psychology at some point involves an understanding of particles, and so on. Mitroff and Turoff make this relativity of meaning very clear: "The point is that all of the models, laws, and facts of sciences are only approximations. All of the hard facts and firm laws of science, no matter how well-confirmed they are, are only hypotheses, i.e., they are only facts and laws providing we are willing to accept or make certain strong assumptions about the nature of the reality underlying the measurement of facts and the operation of the laws. The thing that serves to legitimize these assumptions is the command, in whichever form it is expressed, to take them seriously, e.g., 'take this as the true model underlying the phenomenon in question so that with this model as a background we can do such and such experiments'. Thus, for example, the Bohr model of the atom is not a 'factually real description of the atom' but if we regard it as such - i.e., if we take it as 'true', we can then perform certain experiments and make certain theoretical predictions that we would be unable to do without the model. What Singerian inquirers do is to draw these hidden commands out of every system so that the inquirer is hopefully in a better position to choose carefully the command he wishes to postulate" (16). In effect, the Singerian inquiring system shows how it is possible to sweep ethics into the design of every system (15,16).

What a difference this makes to the world of science and engineering! The Singerian concept challenges over-emphasis on logic-mathematical reasoning which has made "quantitative truth" more acceptable than "qualitative truth" in sciences, without denying the significance of either (l4). In a sense, it undoes Francis Bacon's edict that "when you speak, offer data and information rather than beliefs and judgments." It calls for understanding and reminds us that without beliefs and judgment data and information loose their meaning and potency. The essence of the Singerian inquiring system is complexity and circularity of concepts. These motions are ushering in a profound change in the way sciences are exploring the reality.

The potency of the suggestion that we are in the midst of a radical transition in our scientific thinking does not arise only from system-oriented philosophy. Many scientists and engineers are developing the unsettled feeling that something new and vague is afoot.

Read Nobel Laureate thermodynamicist Prigogine, in his collaborative work with Isabelle Stengers, <u>Order Out of Chaos</u>, where he writes that "our vision of nature is undergoing a radical change toward the multiple, the temporal, and the complex...in the past few decades, something very dramatic has been happening in science, something as unexpected as the birth of geometry or the grand vision of the cosmos as expressed in Newton's work. We are becoming more and more conscious of the fact that on all levels, from elementary particles to cosmology, randomness and irreversibility play an ever-increasing role. Science is rediscovering time"(6). In the world of Newton's dynamics time is reversible. A moment, whether in the present, past, or future, is assumed to be exactly like any other moment. In the new science this is not so.[6]

Alvin Toffler in a foreword to Prigogine's work, referring to Prigogine's hypothesis writes "...the old 'universal' are not universal at all, but apply only to local regions to which science has devoted the most effort. Traditional science in the age of machine tended to emphasize stability, order, uniformity, and equilibrium. It concerned itself mostly with closed systems and linear relationships in which small impacts uniformly yield small results." According to Toffler, the Brussels School of which Prigogine is a founder, is preoccupied with disorder, instability, diversity, disequilibrium, non-linear relationships, and becoming (instead of being) in which small inputs can trigger massive consequences, i.e., they are concerned with reality. In fact, Newton's world is a very abnormal world. "It needs a fantastic imagination to imagine it everywhere as classical sciences does.

Prigogine, in hypothesizing that the order and organization can actually arise "spontaneously" out of disorder and chaos through "self-organization" by a sequential deterministic process followed by chance taking, at sensitive bifurcation points, challenges the notion of cause and effect even more so than Singer's concept of producer-product and statistical dynamics of quantum mechanics. In both the Singerian notion of producer-product and the statistical dynamics, the basic notion of cause-effect is preserved. The notions of probability and producer-product both acknowledge the sovereignty of cause and effect. In these world views, it is human ignorance that prevents us from understanding. In Prigogine's bifurcation points hypothesis, it is the nature that does not know what it will do next. If this be true its implication for science and technology is enormous.

ENGINEERING IN THE SYSTEMS AGE - Russell Ackoff in his book Scientific Method. points out that the meaning of science is not fixed but is an evolving concept (18). He tentatively defines science, in addition to being a body of knowledge, as a process of inquiry. He points out that not all inquiry is scientific. He compares science with common sense and rejects the proposition that the differences are due to either subject matter, immediacy of the problem involved, or a quality versus quantity orientation. It is to be noted, he asserts, that much of today's common knowledge and common sense are based on the products of yesterday's science. What separates science from other inquiries is the approach (18). And the approach could be either of previously described inquiring systems. The nature of the problem and the purpose of the inquiry dictate how these inquiring systems are to be used effectively. Leibnizian, Lockean and Kantian systems may be appropriate for "well-structure" problems, but Hegelian and Singerian systems will be needed in dealing with the "ill-structured" ones. Engineers more frequently than scientists deal with ill-structured problems. Note the following example from the life of a civil engineer.

Dams, large and small, are built all over the world to provide water storage for the multiple purposes of flood control; municipal, agricultural and industrial water supply; hydroelectric generation; recreation; navigation; fishing; etc. Many of these purposes,

[6] Prigogine the dichotomy between the "two cultures" is to a large extent due to the conflict between the temporal view of classical science and the time-oriented view that prevails in a large section of social sciences and humanities. The new science may bring these two cultures together.

however, are in conflict with one another due to the nature of the technology involved. For example, to use a reservoir for flood control, it must be kept, whenever feasible, empty, but for water supply it should be kept, whenever feasible, full. Both demands cannot be satisfied at the same time! Because different groups of people are interested in flood control or water supply, it is easy to see why this physical impossibility gives rise to conflicts among people, attracting political, economic, and ecological forces into play. Therefore, the question of how to design and build a dam - an engineering task - is not the only question that can be asked about building a dam. Other questions need to be answered. What kind of reservoir should be built? Can a compromise be made between flood control interests and water supply interests? Why build a dam at all? And a host of others.

The question of building a dam which involves the knowledge of hydrology, soil mechanics, structural engineering, construction materials, transportation, etc., is quite a different, although interrelated, question than why to build the dam in the first place.

Once one has asked this later question, one must be concerned with a multitude of new questions. What are the impacts on the landscape of constructing and building a dam and creating a reservoir? Who are the people that must relocate and what will happen to them? Which flora and fauna will be impacted and in what ways? Which riches of the earth will be lost forever under the reservoir? Which industry will be attracted and what will the economic influence of the dam be on the cultural life of the region? Which health problems should be safeguarded against? Which and in what way will cemeteries and other historical sites to be relocated. Other questions may be asked and it may be decided that while there is a need for a supply of water there is no need for a dam! One may find, as usually is the case, that the real question is not one of building or not building the dam but how to wisely manage our water resources (a larger system). As the question of building the dam is explored in the context of the development of water resources, one is forced to examine alternatives - control of growth, conservation, water conveyance using pipes and conduits, reuse and recycling, substitution, etc. These are complex questions which have a great deal to do with dam building but also loaded with political, economic, religious, and social implications. Therefore, the significant question may turn out to be how to convert a win-lose situation to a win-win situation, i.e., how to resolve conflict. In short, as the circle of inquiry expands the nature of the question changes and technology becomes in turn both the cause and the solution to the problem.

The most important implication of system thinking is that almost every problem that is perceived to be well structured is at best really an approximation of an ill-structured one, and it depends on the purpose of inquiry whether or not the approximation is acceptable. At the frontier of science every problem and every question is a complex one and requires the application of analytic-synthetic methodology. In search of the truth, reductionism must be supplemented with embedding process.

SYSTEM’S BOUNDARY- It is a common criticism of the embedding process that its application enlarges the scope of the problem under study to unmanageable size. Every time we wish to solve a problem, the critics say, we cannot become preoccupied with the problem of universe. Someone has to solve small problems. For quite sometime I had difficulty in responding satisfactory to this criticism. As an engineer I fully appreciate the need for dealing with manageable systems. But now I think I understand what I did not understand before and believe that I have an answer.

Expansionism means embedding a system under consideration in a larger system of which the first is a part for the purpose of understanding the first system's emerging properties. The system concept tells us that there is no other way, that we know of, that this can be done. However, the problem with embedding is that the process enlarges the problem under study and inevitably will end up at the level of the universe! This, of course, makes dealing with a problem impractical. We need to know how the boundaries of a functional system are determined. We need to know which entities can be ignored without distorting the desired function of the system. In other words what entities of this world belong to the system under study and what entities do not? Churchman instructs us to ask two questions: 1) does the entity affect the purpose of the designer, and 2) does the system have control over such an entity? If answers to both questions are "yes" then the entity belongs to the system. If the answer to the first question is "yes" but the answer to the second question is "no," the entity belongs to the environment of the system and should be treated as a co-producer of the design. If answers to both questions are "no" then the entity can be ignored.

However, the answer to question 1 must be based on the strength or weakness of the impact of entity on the purpose of the design. Those entities that show clear and strong influence on the desired property of system should be included. However, for those entities that do not show clear and strong influence the question of inclusion is not a scientific question. It is a concern of the esthetics of the system. The inclusion decision is an art, exactly in the same sense that art is understood in painting or some other art forms. How did Leonardo know that a certain shade of color on a canvas would create Mona Lisa's mysterious smile? Something deep down in him somehow miraculously inspired him. In system thinking, what entity one considers important to his/her purpose depends on his/her sense of systems aesthetics. Some fifteen years ago the steel industry considered the problem of recycling the cans they were producing for the beer industry outside of their business. In contrast, the aluminum companies did not. Today, you cannot buy beer in steel cans in the U.S. anymore, despite the fact that the cost of producing the steel can is about the same or less than the aluminum can. The managers of steel industry considered that recycling was not important to the business of making steel, but the managers of aluminum industry adopted it as a part of their system.

The inspiration that allows one to select the boundary of a system can be facilitated by an analytic and synthetic approach but in the end the individual's creativity is the key. This is why we need to explore ways of becoming more creative.

EPILOGUE - In one of our recent Engineering Faculty meetings, one of the professors who heard a cursory explanation of systems thinking expressed the opinion that all this system talk sounds fine but perhaps it should be taught at the business school or in arts and sciences, not in engineering. He was in fact questioning whether or not the system approach is a scientific approach or something else. The answer to this question seems to me both yes and no but in the context of systems thinking it is a non-question anyway.

The answer is no if one is a die-hard dynamist or a Newtonian physicist. If one believes that science <u>only</u>, and the emphasis is on only, speaks in the language of quantification, reversibility, determinism, cause-effect, and analysis; then, of course the system approach is not a science. If one believes that science is the study of a certain specific aspect of the "objective" world and then proceeds to define "objectivity" in a very narrow, limited and incorrect sense, then of course the system approach is not science.

On the other hand, I have taken all these pages to show that 1) science, in addition to being a body of knowledge, refers to controlled processes by which men search for the truth, 2) historically this search takes the form of various inquiring systems, and 3) the "systems age" inquiring system, SingerianChurchman, embodies all other inquiring systems in a comprehensive, integrative fashion; then of course the system approach is scientific. The system approach is a way of comprehensively thinking about the "real' world and instructs us to examine it from various perspectives, one of which is the classical science. Classical science was exclusively concerned with particles and their movements and built a magnificent conceptual edifice which has practical usefulness in the range of most human experience, although in doing so created a fantastically unbelievable world! It ignored irreversibility, complexity, emergent properties, indeterminism, complementarily, open systems, "becoming" and all that the real world is about. Yes, the system approach is a very scientific way of looking at our world.

Finally, the question is a non-question because in the context of new ways of viewing the world it is meaningless. I heard someone say that "the universities have departments, the real world has problems." Problems can be solved, resolved, or dissolved as the case may be, but none can take place if one insists on using the tools of one single discipline, not even problems in physics. At the frontier of knowledge disciplines melt into one another and the search for truth becomes a universal expression of intelligent men. The physical world and the symbolic world merge to erase artificial boundaries that university politics have erected.

"The task of science" wrote Niels Bohr, "is both to extend the range of our experience and to reduce it to order" (13). The systems approach does both.

Acknowledgement

As a student of system approach I am indebted to many, but particularly to Russell Ackoff, a colleague, friend, and teacher of some thirty years. Much of my thinking is influenced by him and by West Churchman, who once told me that as an engineer I cannot stand ambiguity. My answer was "how come I have read most of your books and enjoyed them all! Remembering John Kenneth Galbraith's designation of the three most influential books in the history of mankind: the Bible, Adam Smith's Wealth of Nations and, Karl Marx's Das Capital - all very ambiguous works. I have learned to accept ambiguity.

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