COVER OUTSIDE

AN ESSAY ON COMPLEXITY

by

John N. Warfield

September, 1995

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Title page

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ABSTRACT

Complexity is a state of mind[1], triggered into emergence by unsuccessful efforts to comprehend a system immersed in a problematic situation.

Among the false prevailing beliefs about complexity one finds the view that complexity is located external to the observer. This belief misdirects inquiry, and is responsible for human failures to correct the conditions from which complexity arises.

Numerous experimental studies reveal three Definitive Features found in all of the problematic situations studied, suggesting that they are the primary descriptors of complexity. These three descriptors are illuminated by research studies that (a) quantify combinatorial limits on the human mind, (b) reveal wide variation of individual belief when a group of people is confronted with shared complexity, and (c) demonstrate ability to recover from complexity, through systematic application of structural thinking.

Four measures of complexity are defined which reflect the studies. Three of them reflect component measures, and the fourth, the Situational Complexity Index (SCI), quantifies their cumulative impact. By placing the SCI on a logarithmic scale, 0 can represent the absence of complexity, and numbers lying at 3 or above signal its ubiquitous presence. Numbers 1 and 2 on the logarithmic scale identify transitional situations, not to be definitively classified as origins of complexity. Values of SCI are tabulated from a collection of instances defined through work at the Ford Motor Company, on a variety of complexities involved in managing the automotive business.

Complexity can be reduced, perhaps dramatically, using a three-stage reduction process, which has been illustrated in action by the work of Professor Henry Alberts, in leading the redesign of the U. S. Defense Acquisition System. Values of SCI from that effort are also shown.

Prevailing false assumptions about complexity and some of their negative impacts are identified. These false assumptions are propagated, directly and/or indirectly, by institutions of higher education. Changes in these institutions are essential, to decrease complexity and enhance human capacity to improve the effectiveness of systems.

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Complexity is a state of mind. That state of mind is activated through determined inquiry, when a certain threshold is crossed. That threshold is crossed when the person becomes engaged in striving to comprehend a "problematic situation" and, in the process, recognizes that this effort is not successful. If all elements of inquiry are present, but the lack of successful comprehension is not recognized, complexity is **not** present, but the likelihood of misguided followup to the inquiry is very high.

That this description of complexity is accurate may be seen by imagining that the human mind could comprehend whatever situation it confronts. Then it would not matter what attributes the situation might encompass. There would be no difficulty of comprehension, and consequently no complexity. Evidently, then, limitations of the human mind are necessary, if complexity is to have significance. It is also true that necessarily there must be something to drive the human mind into its recognition of complexity; but that can be called a "stimulus" of complexity rather than assigning the attribute of complexity to it.

America's greatest native-born physical scientist, J. Willard Gibbs (1839-1903), who studied thermodynamic systems, chose to define "system" as follows:

"any portion of the material universe which we choose to separate in thought from the rest of the universe, for the purpose of considering and discussing the various changes which may occur within it under various conditions".

Typically, it is a system, in the sense of Gibbs, contained within the problematic situation which cannot be adequately comprehended, and which drives the inquiring mind beyond the threshold of normal understanding into the domain of complexity: the realm where the system is not understood. Typically it is the urge to understand a system, in the sense of Gibbs, with the prospect in mind of changing it, that initiates the inquiry which produces individual frustration due to lack of understanding.

THE MISPLACED ORIGIN. It is extremely common for the human being to place the origin of complexity in the system that is being considered, rather than in the mind of the observer[2]. Even when the system is, itself, present **only** in the thoughts of the observer (i.e., refers to no phenomenon outside the human), the inclination is to attribute the complexity to the system. **To misplace the origin of complexity in the object of inquiry, instead of in the mind of the observer, is to commit an error that is unlikely to be undone.** The phrase "complex system" is only applicable as a shorthand version of "**a system which I tried to comprehend, and could not, due to my limited capability for perception and my physiologically-constrained mental processes**".

RECOVERY. To recognize the true origin of complexity as lying in the mind of the observer is to take the first step toward recovery from the mistakes caused by misplacing the origin of complexity. Of course it is true, as stated previously, that the system being considered is a necessary presence, in order to spur the inquiring mind beyond the threshold, into the domain where complexity is recognized as such. But if complexity lay in the system, one could imagine that the complexity might be permanently obliterated by appropriate human effort external to the observer. **If, however, it is correctly realized that complexity is in the mind of the beholder, the possibility of reducing the complexity through learning processes comes to the fore.**

MULTIPLE OBSERVERS. Once it is recognized that complexity is a state of mind, a question arises as to similarities or differences in the states of mind of multiple observers.

Suppose that one individual from a group of observers truly understands the system, although the others do not. We can imagine that this particular observer, given enough time and resources and access to the others in the observer group, would very likely be able to eliminate complexity altogether, if the others were interested in this outcome.

Yet there would still be irritating questions concerning how the single observer attained freedom from complexity in the problematic situation, and by what means the single individual could convince the others of that condition, thereby eliminating complexity as a concern, by inducing understanding on the part of all members of the group.

EXPERIMENTAL STUDIES. Experimental studies targeted to complexity have been conducted through indirect means for over 20 years. These studies were carried out by facilitating the efforts of groups to resolve situations hypothesized to be complex, in the sense that no member of the group was assumed to understand the system being explored: an assumption easily seen to be valid by observing the groups in action.

In carrying out these prolonged studies, with many groups, involving many systems, three **Definitive Features** were found to be present in all instances:

- *A Plethora of Component Problems.* Through group processes, many component problems relevant to the problematic situation were identified and clarified, each problem being one facet of the system under study. (We will denote the number of such problems as **N**.)

- *Widespread Difference of Belief Concerning Relative Importance.* Individualized voting by members of the group displayed widespread difference of opinion among members on the relative importance of problems involved in the system being studied. (This pervasive condition has since been dubbed "Spreadthink". We will denote the number of problems selected from the set of N which received group member votes as lying in the top 5, in terms of importance, as **V**.)

- *Large Numbers of Dependencies Among the Selected Problems.* By structuring dependency relationships among the V problems, it was discovered that there were large numbers of dependencies among the problems, which is characteristic of problems with systems that induce complexity in the minds of observers. (We will denote the number of distinct paired dependencies among the V problems as **K**.)

In light of the inevitable appearance of these three Definitive Features in the prolonged study of hypothesized complexity, it was decided that the three accompanying numerical measures ought to be recognized as numerical measures of complexity. It was also felt that this recognition should be connected to results of theoretical studies, i.e., those that offered scientific bases for applying these measures to assess complexity.

PUBLISHED RESEARCH RESULTS. Since complexity is a state of mind, and since it appears always to involve (a) numerous component problems in the system under study, (b) significant differences in the views of inquirers and (c) numerous paired relationships among component problems; it is appropriate to identify research publications which describe how or why the Definitive Features relate to complexity.

Combinatorial Limitations on the Mind. Combinatorial limitations reflect inability of the mind to work collectively on an idea set and the interactions among the members. Study of these limitations is reflected in several publications[3] which, collectively, show (a) why N, when significantly greater than 7, contributes to the threshold beyond which

complexity dominates and (b) why K, reflecting pairs of relationships, likewise drives the mind beyond the threshold.

Variation of Individual Belief. Extensive data on wide variations in individual belief have also been discussed in the literature[4].

Recovery from the Impact of Complexity Through Structural Thinking. While shedding light on why and how the three Definitive Features contribute to complexity, it has also been shown how recovery is often made possible through well-designed processes that emphasize "structural thinking"[5].

MEASURES OF COMPLEXITY. Since human beings, acting alone, frequently are capable of understanding situations, but since they are incapable of understanding problematic situations that induce complexity, necessarily there are at least two types of situations: "ordinary" and "complex". The former could refer to those situations where individuals are capable of understanding, and of basing actions on that understanding. The latter could refer to those situations where complexity arises. It also seems likely that there could be a region where situations could not readily be placed in either category. In that respect, it seems that **the appropriate designation of situations into categories** could be:

- *Ordinary Situations*: those where individual understanding is commonplace
- *Transitional Situations*: those where it is unclear whether the situations are ordinary or complex, and whose classification may depend upon the particular observer that is involved
- *Complex Situations*: those where complexity is recognized, and the situational classification is considered to be observer-independent

In today's world, the relevant distinctions are not being made. Individuals and organizations alike, seldom distinguish a situation according to these classifications and, when they do so, they seldom construct strategies for change that reflect the classification. Consequently it appears that many disasters occur because of human inability or unwillingness to accept the presence of complexity. There is abundant, observable evidence of this situation in the constant bombardment of news involving catastrophes and disasters all around the world. Senator Daniel Moynihan, in his academic days, wrote about the neglect of complexity as follows[6]:

"Anthropologists tell of a people so indifferent to complexity that the whole of their numerical system consists of the terms 'one', 'two', and 'many'. And yet how close to our own reality they are...Political society wants things simple. Political scientists know them to be complex. This is no small matter...One could argue that, in part, the leftist impulse is so conspicuous among the educated and well-to-do precisely because they are exposed to more information, and are accordingly forced to choose between living with the strain of complexity or lapsing into simplism...It may be that...a period of ever greater complexity will be necessary before things start falling into place and grow simple again. It may be that things will never fall into place..."

In considering the willingness to come to grips with complexity, Moynihan concluded that, at the time his article was written:

"A tentative answer would have to be that neither the will nor the capacity to do so exists in sufficient degree to make an impress on social policy."

In light of what has just been said, a reason for measuring complexity comes into view: to make it possible to categorize situations in order to make it clear when a situation is complex, so that responsibility to take complexity into account can be clarified. Then as a followup, efforts to cope with complexity should be subjected to "due process" demands, in order that the processes applied should be demonstrably capable of yielding the necessary insights to govern human action. Capricious actions

that affect negatively large populations should be viewed as socially unacceptable.

In view of the possibility that sanctions ultimately may become respectable to help preclude behavior that ignores complexity, it is appropriate that measures of complexity be conservative. Situations that probably should fall into the domain of Complex Situations can, if not completely clearly so classified, be consigned, at least temporarily to the realm of Transitional Situations. **But there must be some threshold above which complexity is seen manifestly as present, at dangerous levels.**

With this philosophy, the development of measures of complexity becomes the next subject of this paper.

Complexity Scales and Reference Values. How shall a scale of complexity be determined? And how shall origins or other reference values on that scale be decided?

The three Definitive Features, and the associated designations of measures form a set {N, V, K} whose values can be determined in problematic situations by conducting established group processes. Each of these numbers, as previously indicated, corresponds to interpretations from the research literature. So it is to that literature that recourse can be made to incorporate values from this set.

In assessing a scale for complexity, two prototypical schemes can be chosen from previous choices of scales in unrelated areas. In one scheme, a simple algebraic computation is carried out to assign a value to a scale. In the other scheme the logarithms to the base 10 of the algebraic computation are used. The algebraic values often span very large ranges. When logarithms are used, the numbers tend to be within a particular range, and are easier to remember and to compare with one another. There is no necessity to have just one or the other scheme. Instead, both can be applied, each as appropriate.

There is an established practice in the physical sciences which can appropriately be adopted in choosing a scale. That practice is to talk about "orders of magnitude". This usually refers to powers of 10. Thus something that is expressed as approximately 10^6, for example, when compared with something that is expressed as approximately 10^2 would be declared to differ by four orders of magnitude. The number four is found simply by taking the difference between the two exponents. With this type of scale, it is often true that two numbers sharing the same exponent, e.g., 4×10^6 and 1.37×10^6 can effectively both be regarded as on the order of 10^6 without giving attention to the numerical multipliers.

That is because, on the one hand, precise replicability cannot be attributed to the experimentally-derived numbers, and on the other hand, it is often true that it is **relative** (rather than **absolute**) values that are important. The important attributes may be determined by the exponent, without regard to minor variations.

If logarithms are used with the numbers just cited, the two that share the exponent 6 would both be represented by that exponent, while the number that has the exponent 2 would be reflected by its exponent. Both numbers would then fall in the limited range between 1 and 10, which is sufficient to accommodate many phenomena. (The well-known Richter Scale to describe earthquake intensity has logarithmic features, so that an earthquake with value 8 is much more than twice as powerful as one with value 4 on the Richter Scale.)

These are matters of convenience, and reflect uncertainties in quantification stemming from variations among groups.

With these remarks in mind, and with reference to the research results, four indexes of complexity are defined herewith, each being expressible in a value associated with an algebraic form; each being likewise expressible in a value associated with the logarithmic form (adjusted to integer values) that corresponds to the algebraic form. Examples of this scheme will appear later in this paper.

With the two forms, the value 1 will represent the reference value for the algebraic scheme, and the value 0, which is the logarithm to the base 10 of the algebraic value 1, will be the reference value for the logarithmic scheme.

Complexity Indexes. Four indexes of complexity will now be defined.

The Miller Index. Let the quantity N/7 be identified as the **(algebraic) Miller Index**. This nomenclature refers to George Miller, who first published an analysis of quantitative capability of the human mind in his often-cited paper concerning the "magical number", referenced earlier in this paper. If N = 7, the algebraic Miller Index is equal to 1, and the number 1 can then be taken as a reference point. It seems appropriate, for general applicability, to use a logarithmic value, and to restrict it to integer values. Therefore, in the recommended representation, for the **(logarithmic) Miller Index m_c** is:

m_c = 0, if N is less than or equal to 7;
m_c = 1, if N takes a value between 8 and 99;
m_c = 2, if N takes a value between 100 and 999;

and so on. So far, values of N from practice have been found largely to lie between 40 and 160, for which the logarithmic Miller Index is 1 or 2.

The Spreadthink Index. Let the quantity V/5 be identifed as the **Spreadthink Index**. "Spreadthink" refers to the variability of belief about relative importance of component problems of a problematic situation that characterizes individuals working in groups. If V = 5, the **(algebraic) Spreadthink Index** takes the value 1, which corresponds to total consensus. By analogy with the definition of the logarithmic index value discussed previously for the Miller Index, the **logarithmic Spreadthink Index s_c** is:

s_c = 0, if V = 5,
s_c = 1, if V lies between 6 and 499,

and so on for other values of V. Normally V will exceed 5 significantly, but will be significantly less than 499, so the normal expectation for the value of s_c is 1.

Some might wish to argue that by defining the Index in this way, an extremely coarse measure results. This argument is perfectly true. But one may keep in mind that the measures are used almost (not quite) exclusively as threshold numbers to help determine whether a given problematic situation is complex or not. In fact, it seems advisable to use the definitions as given, just to try to assure that zealots of numeracy will not try to read more into the definition than is required or appropriate. Sometimes, as will be illustrated shortly, the measure will be used to make coarse comparisons of **relative** complexity of several problematic situations.

The DeMorgan Index. Let the quantity K/10 be identified as the **(algebraic) DeMorgan Index**. This name is chosen to honor Augustus DeMorgan, the inventor of symbolic notation for relations[7]. The number 10 corresponds to that degree of relationality represented by a linear structure involving 10 relationships among 5 problems, thereby correlating with the situation where a group agrees on the 5 most important aspects of a situation. When the algebraic DeMorgan index is 1, it means that the relations among components of a complex situation are modest in number, and very likely manageable. For values exceeding 1, and departures from linearity of structure, the DeMorgan index is a measure of the extent of relationships among identified components of the complex situation.

By analogy with the foregoing, the logarithmic DeMorgan Index d_c is defined as follows:

d_c = 0 if K is 10 or less;
d_c = 1 if K lies between 10 and 100;
d_c = 2 if K lies between 101 and 1000;

and so on. In applications, d_c has been found to lie typically between 101 and 1000, so a normal expectation is that this index will take the value 2.

Situational Complexity Index. The (algebraic) Situational Complexity Index is defined as the product of the three algebraic indexes just defined. The logarithmic Situational Complexity Index then is the sum of the other three indexes. Specifically, the **logarithmic Situational Complexity Index, I_c**, the composite or overall index of complexity, is defined as follows:

$$I_c = m_c + s_c + d_c$$

If all three of the constituent indexes take the value 0, the composite index likewise is 0; but if any one of the three components takes the value 1, the composite index will be greater than or equal to 1.

In the applications studied to date in which complexity was present, $m_c = 1$ or 2; $s_c = 1$; and d_c lies in the range from 2 to 4, inclusive. Consequently, **typical values of I_c from applications lie between 4 and 7.**

Based on all of the definitions, and the experience to date with several hundred problematic situations perceived to involve complexity, the arbitrary rule for determination of complexity for a problematic situation is as follows:

The Classification Rule. *If the composite index, the Situational Complexity Index I_c, is 3 or greater, the situation should be classed as "complex". If it is 0, the situation should be classed as "ordinary". If it is 1 or 2, the situation should be classed as "transitional".*

Typical Values of the Indexes for Various Situations. Table 1 shows values of the various indexes stemming from 12 Interactive Management Workshops held at the Ford Motor Company, and from a series of approximately 30 Interactive Management Workshops conducted for or by the Defense Systems Management College (DSMC), Fort Belvoir, Virginia. Data are provided for each of the Ford projects, and for the composite results of the DSMC project, which extended over four years[8].

THREE-STAGE REDUCTION OF COMPLEXITY THROUGH STRUCTURAL THINKING. Given the indexes, it is possible to consider how complexity can be reduced, by showing how the indexes can be affected through the application of a three-stage process. The specific problematic situation used to illustrate this reduction is the U. S. defense systems acquisition process. This situation provided the information represented in the last three rows of Table 1. The three stages are here described as the "Operational Stage, the Tactical Stage, and the Strategic Stage", where these names are arbitrarily chosen to reflect somewhat standard usage in the management of large organizations.

In the Operational Stage, as indicated in Table 1, 678 problems relative to system acquisition were collectively identified by more than 300 program managers who were active in defense acquisition management. In the Tactical Stage, these 678 problems were placed in 20 tactical categories. Finally, in the Strategic Stage, these 20 categories were placed in 6 strategic domains.

As shown in Table 1, the value of the Index of Situational Complexity was computed to be 7 for the first stage, 4 for the second stage, and 2 for the third stage. Keeping in mind the logarithmic nature of these indexes, the first stage was 5 orders of magnitude more complex than the final stage. The final stage was 2 orders of magnitude less complex than the second stage.

In his dissertation, previously referenced, Professor Alberts indicated that one of the two main objectives of his work was to use that work **to represent a prototype process for organizational redesign**, a very complex application of a designed process for reducing complexity. The three-stage process applied in this work might well involve only two stages in many areas of complexity. A fourth stage might be required in some instances. As shown in his dissertation, the new design was expected to resolve about 90% of the problems. There remained about 70 problems unresolvable in this design, originating from outside the acquisition system, which could not be resolved through exercise of internal powers.

It is fair to say that the complexity was reduced dramatically as the work progressed through the three stages. **This reduction is reflected in the staged decreases in I_c from 7 to 4 to 2.** When completed, a highly transparent representation of the acquisition system was available. This allowed persons in the operational aspects of acquisition to relate the problems they work with every day to the higher-level categories; and vice versa. As a result, a redesign of the system could be carried out that reflected high visual capability in connecting design options to problems at all

TABLE 1. DATA RELEVANT TO INDICES OF COMPLEXITY

Project Number	N	V	K	Logarithmic Index Values			
				m_c	s_c	d_c	I_c
F1	127	35	230	2	1	2	5
F6	81	42	202	1	1	2	4
F8	76	37	110	1	1	2	4
F9	58	23	137	1	1	2	4
F10	103	33	323	2	1	2	5
F12A	48	34	157	1	1	2	4
F12B	59	32	243	1	1	2	4
F12C	63	25	272	1	1	2	4
F13	73	29	263	1	1	2	4
F15	112	47	508	2	1	2	5
F16	71	30	813	1	1	2	4
F19	131	51	354	2	1	2	5
D-O	678	339*	28,900*	2	1	4	7
D-T	20	20**	180	1	1	2	4
D-S	6	6**	15	0	1	1	2

The prefix letter F in the first column identifies the row with the Ford Motor Company. The succeeding number keys the row to a particular Ford IM Workshop. The prefix letter D in the first column identifies a set of approximately 30 workshops held by or for the Defense Systems Management College. The letters O, T, and S accompanied by the prefix D refer to "Operational", "Tactical", and "Strategic", respectively, although those terms were not used in the IM Workshops.

* A single asterisk means that the value was estimated. ** A double asterisk means that the value was not determined, but the value used for computation is the maximum possible value.

three levels. It is very likely that because of this extensive referential transparency, the relevant legislation passed by the U. S. Congress involved only minimal modification to the results coming from this work. The legislation, identified as Public Law 103-355, October 13, 1994, is cited as the "Federal Acquisition Streamlining Act of 1994".

SOCIAL CHANGES THAT CAN RELATE TO COMPLEXITY. Numerous past activities in society have generated complexity; supported the continuance of complexity; and ignored systematic, scientifically-based methods for coping with complexity. A major probable cause of this has to do with the prevalence in society of long-established, false assumptions. Social changes that could be based in corrective measures hold the potential for major improvements.

In order to see why this is so, some of the prevailing false assumptions will be identified, some of their impacts will be noted, and some corrective measures will be set forth.

Prevailing False Assumptions. The most damaging false assumptions involve one or more of the following:

- Science
- Language
- Validity
- Processes
- Contexts

For these five topical areas, one must remember to see them in the context of complexity, **not** in terms of ordinary situations.

False Assumption About Science. It is falsely assumed that science (as a body of knowledge) is changing rapidly. This false assumption is commonly made in working with complexity.

It is technology that is changing rapidly. Science is changing slowly.

False Assumption About Language. It is falsely assumed that language is adequate to describe, diagnose, design, and implement complex systems.

Complexity requires that language be developed of the highest flexibility, while preserving definiteness, and that persons working together with complexity must share a linguistic domain that cannot be delivered to them from external sources, but must be developed through dialog, systematically carried out.

False Assumption About Validity. It is falsely assumed that validity of ideas applicable to ordinary situations carries over to complex situations.

This false assumption underlies widespread activities aimed at dealing with complexity using methods and ideas whose validity rests only on experience with ordinary situations; and which are unresponsive to the demands of complexity.

False Assumption About Processes. It is falsely assumed that the choice of processes for working with complexity is domain- or discipline-sensitive; e.g., each department of a university must have its own discipline-distinctive processes.

The processes relevant to complexity must be driven by the demands of complexity, and not by domain or disciplinary requirements. What is domain- or discipline-distinct is the **content**, and its proper development requires the use of domain- or discipline-independent processes, tailored to the demands of complexity.

False Assumption About Contexts. Particularly in higher education, it is falsely assumed that each discipline or domain should freely choose the knowledge context within which it operates.

While free choice of content within a context is essential, the chosen context must reflect the social demands of complexity. Context, as it relates to disciplines, has to be defined and negotiated participatively, in an open setting where comprehensive concerns are addressed to integrative requirements of applications. Only after those concerns are negotiated, can domains or disciplines attain the quality required to meet the demands of complexity.

Consequences of the False Assumptions. The consequences of the false assumptions just described are individually damaging, and collectively devastating.

Consequences of False Assumption About Science. If it is assumed that science (as a systematized body of knowledge) is changing rapidly, many people (educators and practitioners alike) will choose not to attempt to stay apace of the change, in the light of more pressing demands on their time, as well as the absence of adequate supporting infrastructure. This means that they will be much more susceptible to views imposed by presumed authority (the "prestigious" organization), aggressive consultants, and to "groupthink". On the other hand, if it were assumed that science is changing slowly, a decision to stay apace with the change would be much easier to make.

A mature view of the slow pace of science would also support a much stronger effort to keep technological and organizational changes linked to science--not only for purposes of providing scientific footing for those changes, but also for stimulating scientists to take advantage of practitioner-generated information and experience to test the solidity of the science. Then both science and applications could be strengthened, through their mutual association. **The only significant means of quality control of practice in scientifically-based activity is through this kind of comparison.**

But perhaps the greatest negative impact of this assumption arises by confusing science with technology, confusion that has been supported by mixing them in the public mind by scientists, technologists, managers, and the media. If a substantial majority of managers, leaders, and practitioners are unable to distinguish one from the other, the types of benefits described in the preceding paragraph are lost. One consequence is a continuing deterioration in the quality of knowledge. But still more damaging is the substitution of non-scientific belief for tested results. "Venture literature" of the type that is becoming increasingly prevalent in the latter part of the 20th century substitutes, for archival developments, an appeal to the latest fad.

Consequences of False Assumption About Language. When striving to communicate with one another about complexity, human beings lack the capacity to assess the extent to which inadequate language frustrates their attempts. But data are available that demonstrate quite clearly these aspects of language: (a) the inadequacy of prose to communicate patterns involved in complexity, due to the linearity inherent in prose and the non-linearity inherent in structures of complexity; (b) the inadequacy of typical technological graphics to communicate, because of the ad hoc style used to create such graphics, (c) the undisciplined acceptance of bad graphical patterns as internal standards by educators, governments, and private-sector organizations; and (d) the necessity for collegial group development of **a shared linguistic domain**, in order to make possible high-quality communication about complexity. (The feasibility of achieving this necessity has been clearly demonstrated, and it can occur as a by-product of facilitation in carrying out the Work Program of Complexity.)

Consequences of False Assumption About Validity. The individual develops bad habits, thoroughly reinforced by repetitive educational practices, that cause non-appropriate processes to be applied in working with complexity. Parallel with bad individual habits are organizational bad habits, (i.e., the consequences of the seamier side of cumulative organizational culture) which ratify the use of processes that are inappropriate to meet the demands of complexity, within the organization.

Consequences of False Assumption About Processes. A very distressing consequence of the false assumption about processes is the extreme inefficiency introduced in higher education caused by the practice of each individual discipline to occupy learner time teaching processes that either (a) appear to be limited to application in the individual discipline or (b) if the processes truly are limited to a particular discipline, failing to insist that they be augmented, in the educational experience, with processes that meet the demands of complexity, which are not discipline-specific. But the inefficiency in higher education is relatively negligible

compared with the mammoth social waste when organizations behave in the same way as educational institutions, failing to install and manage processes that meet the demands of complexity across the organization, before moving into discipline- or product-specific activities.

Consequences of False Assumption About Contexts. Virtually all major issues or situations that create significant difficulties in society do not fit disciplinary or institutional categories that define collegial groups. On the contrary, they stretch across those groups regularly and intensively. Still organizations regularly institutionalize contextual inefficiencies and confusion. *Laissez-faire* practices in setting contexts lead to consequences similar to those found in totally-unrestricted economic systems: extreme abuse of human beings by the lower-end entrepreneurs. Keeping in mind that context, content, and process are all invariably involved in learning; the failure to facilitate learning by allowing support to continue for unsatisfactory contexts and processes becomes a major obstacle to progress.

Collective Impact. If it were true that each false assumption operated by itself, the bad consequences would probably be much more apparent, and corrective measures might be locally instituted. But, as seems often to be true, all of these bad assumptions are collectively prevalent in many organizations and in many problematic situations. Then they reinforce one another, with the result that the bad impact of each, individually, is multiplied in the aggregate consequence.

CORRECTIVE MEASURES. Corrective measures aimed at the collective aspects of complexity cited in the foregoing can be sought by the usual approach to inquiry. However there is a comprehensive way to deal with the totality, at least for the present, until something better comes along. That approach is to learn and apply the system called "Interactive Management". This system is based in a science of generic design. The latter, in turn, is based in a preliminary science of complexity.[9]

CONCLUSIONS. Complexity is a state of mind, triggered into emergence by unsuccessful efforts to comprehend a system that is immersed in a problematic situation.

Efforts to cope with or manage complexity are hampered by a variety of incorrect assumptions. Research results are available that correct the perceptions that have produced those bad assumptions.

The research results provide a comprehensive approach to complexity, which is responsive to the demands of complexity.

Educational institutions should recognize their role in helping overcome the bad impact of complexity on human systems.

Practitioner organizations should take advantage of existing science and processes to provide remedies for unconstructive habits and cultural features.

END NOTES

1. Some latter-day authors **equate complexity to chaos theory or adaptive systems theory**. My response to them is this: *"One twig does not a forest make, nor treble clefs a fugue."*

For a discussion of such activity, see the article "**From Complexity to Perplexity**" by John Horgan, in *Scientific American*, June, 1995, pages 104-109.

2. Scholars of semiotics and of constructivism will object to the use of the word "rather" in this sentence, because they will assert correctly that the perception of the system is constructed in the mind of the observer and, for that reason, the distinction involving the word "rather" is irrelevant. Common usage supports the sentence as stated, but that does not mean that the objection is not valid.

3. Three publications present relevant material. They are: (1) G. A. Miller (1956), "**The Magical Number Seven, Plus or Minus Two: Some Limits on our Capacity for Processing Information**", *Psychology Review* 63(2), 81-97; (2) H. A. Simon (1974), "**How Big is a Chunk?**", *Science* 183, February 8, 482-488; and (3) J. N. Warfield (1988), "**The Magical Number Three, Plus or Minus Zero**", *Cybernetics and Systems* 19, 339-358.

4. These three publications describe various aspects of variations in individual belief: (1) D. B. Yntema and G. E. Mueser (1960), "**Remembering the Present States of a Number of Variables**", *Journal of Experimental Psychology* 60(1), 18-22; Kenneth Boulding (1966), **The Impact of the Social Sciences**, New Brunswick, NJ: Rutgers University Press (see especially "spurious saliency"), and (3) J. N. Warfield (1995), "**Spreadthink: Explaining Ineffective Groups**", *Systems Research* 12(1), 5-14.

5. J. N. Warfield (1995), "**Structural Thinking: Organizing Complexity Through Disciplined Activity**", *Systems Research* 12(3), 000-000.

6. Daniel P. Moynihan (1972), "**The Schism in Black America**", *The Public Interest* (27). A longer version was quoted, with permission, in J. N. Warfield (1976), **Societal Systems: Planning, Policy, and Complexity**, New York: Wiley, 14-15.

7. Augustus DeMorgan (1847), **Formal Logic, or the Calculus of Inference, Necessary and Probable**, London.

8. More complete information on the Ford work is given in the paper titled "**Complexity Measurement of Systems Design**" by Dr. Scott M. Staley of the Ford Motor Company, which will be presented at the First World Conference on Integrated Design and Process Technology, Austin, Texas, December 6-9, 1995, and published in the conference proceedings. More complete information on the DSMC work appears in the doctoral dissertation of Professor Henry Alberts, titled "**Redesigning the United States Defense Acquisition System**", City University, Department of Systems Science, London, U. K., 1995.

9. The management system is presented in: J. N. Warfield and A. Roxana Cárdenas (1994), **A Handbook of Interactive Management**, Ames, IA: The Iowa State University Press. The generic design science is presented in J. N. Warfield (1994), **A Science of Generic Design: Managing Complexity Through Systems Design**, Second Edition, Ames, IA: The Iowa State University Press. The preliminary science of complexity is being developed in a manuscript titled: **The Work Program of Complexity: From Origins to Outcomes.**

OUTSIDE BACK COVER

ABOUT THE AUTHOR

John N. Warfield is University Professor and Director of the Institute for Advanced Study in the Integrative Sciences (IASIS) at George Mason University (GMU), a state university, in Fairfax, Virginia. IASIS is a component of the Institute of Public Policy (TIPP) at GMU.

He received the A.B. degree, the B. S. in Electrical Engineering, and the M. S. in Electrical Engineering from the University of Missouri (Columbia) in 1948, 1948, and 1949, respectively. He received the Ph. D. degree from Purdue University (West Lafayette) in 1952, majoring in electronic communications.

He has 38 years of university faculty service, of which the past 12 years have been at GMU. He has spent a total of 20 years as a faculty member in Virginia, and during that time has had the designation "eminent scholar" in the Virginia system. He has about 10 years of industrial experience: Director of Research, Wilcox Electric Company (1965-66); Senior Research Leader, Battelle Memorial Institute (1968-74); Senior Manager, Burroughs Corporation, (1983-84). This experience included research of both theoretical and experimental nature, electronic development and reliability testing of navigational equipment for jet aircraft, and management experience in overseeing research projects and industry-university contracts.

He has served as elected President of the Systems, Man, and Cybernetics Society of the Institute of Electrical and Electronics Engineers, and is a Life Fellow of that organization. He has served as elected President of the Society for General Systems Research (later renamed the International Society of Systems Sciences). He served 9 years as founding editor of Systems Research and four years as editor of the IEEE Transactions on Systems, Man, and Cybernetics.

He is the author of two U. S. patents on electronic equipment, and is the inventor of Interpretive Structural Modeling, Interactive Management, and Generic Design Science.

He is sole author of four books, co-author of another book, and co-translator of a classic German work on communication networks. He is author or co-author of over 100 papers. He is in demand as a speaker and collaborator outside the United States where his research contributions are well-known. He has presented his work on complexity in ten nations, and has taught one-week short courses in five of them.

His primary activities in the past few years have involved preparing two books for publication in 1994, authoring papers, presenting papers at conferences, teaching short courses, and serving as an information resource or an active participant in working with individuals who are seriously dedicated to improving quality, effectiveness, efficiency, communication, and organizational cultures in their various organizations. He is presently preparing a new book manuscript titled: The Work Program of Complexity: From Origins to Outcomes. Biographical sketches of Warfield can be found in American Men and Women of Science, Who's Who in Engineering, Who's Who in Frontier Science and Technology, and Who's Who in America.