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■ *Research Paper*

Twenty Laws of Complexity: Science Applicable in Organizations

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The *'LTI Set'*, consisting of 20 Laws of Complexity, a Taxonomy of the Laws of Complexity, and five Indexes of Complexity, is proposed as the core of a developing science of complexity that is applicable to resolving complexity in organizations. The *LTI Set* links to these included topics:

- Alternative Science-Free Organizational Practices
- Educational Practices Appropriate to Complexity
- Quality Control of Science
- Applications of the Science of Complexity in Organizations
- Enabling Conditions for Effective Organizational Practice

A critical condition for significant advances in resolving complexity is that the organization recognize the strong, even dominant, behavioral aspects of complexity, as reflected in the Laws; and take account of these in redefining the main role of top management. That role is to set up and administer a responsive corporate infrastructure to meet the demands of complexity, along the lines set forth here. Further advances in behavior can be made through new educational programs that reflect older scientific values applied to the challenges of today, in contrast to reliance on unwarranted assumptions that undermine organizations. Appropriately remodeled to reflect the relentless demands of complexity, the university can become a model for other institutions in society.

Keywords applications; complexity; management; organization; science of complexity; structure; university

INTRODUCTION

Three related contributions (a platform triad for a science of complexity) are designated here in set form as {*Twenty Laws of Complexity, a Taxonomy of the Laws, Five Indexes of Complexity*}. In abbreviated form, the triad is referred to as the *'LTI Set'* (*L* for Laws, *T* for Taxonomy, *I* for Indexes). While the Briefs of the Laws represent the focal contribution, they are aggregated in the Appendix to best use available space. The *LTI Set* is augmented by a discussion aiming to integrate these contributions in an organizational

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context in society. The body of the paper is dedicated to the integrative discussion.

The Taxonomy aggregates the Laws into three non-mutually exclusive categories, one of which is further divided into three subcategories. These breakouts help interpret what is occurring in applications, and make possible discussion of the significance of the Laws in the body of the paper, without going overly into details. The Indexes of Complexity provide mutually complementary numerical measures of complexity in any particular application, frequently taking the value 1 as the quantitative base of reference that separates the ordinary (a number less than or equal to 1) from the complex (a value exceeding 1, usually very substantially in applications). Even though the integrative goal dominates the body of the paper, each set and subset of the *LTI Set* is identified in full in the paper.

Linkages to the *LTI Set*

The *LTI Set* is intended to be the core of a science of complexity. But when standing alone it is not sufficient to drive the task begun here to its first plateau. Even if a science of complexity were fully developed, much more than the science would be needed in order to translate that science into a valuable social asset. Since the science offered here is only partly developed it is necessary, in order to stimulate independent assessment and enhancement of this work, to link the *LTI Set* to these topics relevant to a science of complexity:

- *Alternative (Science-Free) Organizational Practices:* Practices carried out in organizations without reference to a science of complexity
- *Educational Practices:* Educational practices to equip people to become involved effectively in drawing value from the science
- *Quality Control:* Quality control in a science of complexity
- *Applications:* Application of the science in resolving complexity
- *Organizational Enabling Conditions:* Organizational conditions required to get maximum benefit from applying the science

ALTERNATIVE (SCIENCE-FREE) ORGANIZATIONAL PRACTICES

It is well known that many practices are presently advocated to promote constructive organizational change. They can be compared and contrasted neither to belittle nor to enshrine them. Instead, one begins with the firm belief that 'one size does not fit all', and the heart of a comparative discussion ought to be mainly devoted to discovering the best role for any given practice to fill, within the universe of organizational change activities. Because there are so many practices [end note 1, involving a reference by Ackoff to 'panacea overload'], a strategy of process role discovery is needed to whittle down the numbers to a manageable set. One component of such a strategy is *to consider only those practices that are offered by their advocates as being relevant to resolving complexity*. Many of the current practices *do not* involve that claim, so they can be excluded from this discussion. A second component of the strategy is to discuss only those practices that, at least superficially, *seem to be connected (or are said to be connected) to science*. With this two-component strategy as a filter, only five schools of thought about complexity appear to merit discussion here, and one of those is distinguished by what on the surface seems to be an indifference to complexity. This discussion makes it possible to say why the *LTI Set* is so critical in choosing a strategy for working with complexity in organizations. When this strategy is used, attention automatically focuses on top management of the organization, which is most likely to be concerned about resolving raging complexity, yet, paradoxically, least likely to be inclined to inject science into its resolution.

The Changing Role of Top Management

Historically the complexity that faces corporations and governments has been dealt with by top management, as possibly its primary responsibility. A typical way to try to cope with the complexity is through strategic planning, possibly consisting of components that focus on

particular time intervals. For example, there might be a package of interrelated plans that look out ten years, five years, and/or two years; connected to and affecting a short-term operational plan that focuses on the year ahead. As planning theory has matured, it has become acceptable to say that, for the most part, the purpose of planning is not so much to say what will be done in advance, but rather to prepare the mind of the executive for decisions that must be made as time passes. Experience shows that attempts to predict reliably what will happen in the future and when it will happen does not generally produce commendable predetermined actions. By having had some vicarious exposure to possible future events during the planning work, the executive is presumed to become ready to tackle whatever comes along in the light of some previously nurtured insight derived, in part, from that planning. When complexity is the focus, and science is omitted from the realm of discussion, assumptions take root as the replacement for science (often overtly, or even subconsciously) [end note 2]. Some of these assumptions can best be described as 'killer assumptions'.

Killer Assumptions

Certain assumptions seem to be locked into the corpus of the practice just described. In order for that practice to be successful, those assumptions must be satisfied. Here are some of the killer assumptions that can undermine that practice:

- *Adequate Executive Capacity*. The executive has the intellectual capacity to comprehend:
  (a) how the various interactions that take place as situations change are interrelated;
  (b) at what time actions should be initiated;
  (c) what alternatives are relevant when the time comes to take those actions.
- *Reliable Organizational Information Flow*. The flow of information in organizations is sufficiently coherent to permit the executive's decisions to be factored into day-to-day operations reliably.

Keeping in mind that the focus here is on complexity, *there is little knowledge to support these assumptions in a scientifically respectable way*. Considerable evidence exists that none of the assumptions mentioned is valid. Perhaps that is why large organizations are undertaking more and more 'off-sites' or 'interventions' from outside, in which small teams work together to try to resolve situations that the older practices cannot cope with. If there is confusion at the highest levels of management concerning how best to proceed, perhaps a beginning can be made by defining the requirements that a complexity-resolving system for managing might be asked to meet.

Defining Requirements for a Complexity-Resolving System

If present approaches to managing complexity (e.g., the US Medicare system, which is variously said to involve many billions of dollars in fraud every year) are unsound, one would hope that researchers would come forth with novel and tested alternatives. In searching for such alternatives, one must constantly keep in mind the question: 'Is this alternative satisfactory for working with complexity, or is it rather something that is best suited to work with lesser matters?' Today, it appears that there is only one alternative (Interactive Management (IM) [end note 3] whose advocates claim that it satisfies all of these *Defining Requirements*:

- *Full Disclosure*. Its explanation is widely available in the literature.
- *Replicability of Activity*. The explanation is in significant depth, so that replication is possible.
- *Specializing in Resolving Complexity*. It is intended only for resolving complexity in organizations.
- *Sizeable Record of Value-Adding Application*. It has been applied in many organizations and has added significant value.
- *Founded in Science*. It is founded in science.

In its early stages, IM was buttressed by a 'science of generic design', because it was felt

that complexity is best resolved by well-thought-out, comprehensive designs. But it was always felt, as well, that design itself needed to be founded in a science of complexity; and that there would be considerable overlap between a science of complexity and a science of generic design. Given that idea, it seems relevant to consider the present state of thought about complexity, in the light of a study of various schools of thought about it.

Schools of Thought about Complexity

The issue of whether other approaches focus specifically upon complexity remains open. But in an effort to close in on the issue, a study was carried out to define 'schools of thought' about complexity [end note 4]. The school that underpins Interactive Management is called the 'Structure-Based School', because it proceeds from the assumption that it is the organization of complexity that must be the foundational way to start to resolve it. The Structure-Based School is not intended to compete with other schools. Rather, because it is more fundamental, it is intended to make it possible for the other schools of thought to accomplish what is required in order for any of those other schools to add value to a situation that is rife with complexity. The Laws given here are consistent with and underpin the 'Structure-Based School'. The four other schools of thought to be identified here generally have not shown awareness of these laws, and might find them inconsistent with their views. Nevertheless, by knowing that these schools exist, the reader will be better equipped to see what is presented here from multiple perspectives.

These five identified schools of thought concerning complexity appear to represent the variety that is active at the present time:

- *The Indifference School.* Two (non-mutually exclusive) academic subgroups can be described as examples of members of what constitutes a very large Indifference School (by no means confined to academia). These subgroups are characterized either (a) by what may be called Interdisciplinary 'approaches' or 'methods' (e.g. fostered by the Association for Integrative Studies, a predominantly liberal-arts-faculty activity) or (b) as the 'postmodernists' who appear to challenge all organized knowledge. Neither subgroup recognizes complexity overtly in its philosophy or in its practice.

Three schools may be characterized as today's version of the Comte-engendered 'positivists' or as today's technical representatives of 'scientism' as described in great detail [end note 5]. These schools prefer not to deal overtly with the logic foundations of their models, but prefer rather to 'invent' methodologies that are not required to be supported by any underlying science. They consist of the 'Systems Dynamics' school, the 'Chaos Theory' school, and the 'Adaptive Systems School'.

All actively promote models that essentially shut out the human being as an active component of a system, and draw much of their reasoning directly by analogy with mathematical systems of varying types, mostly consisting of some form of differential equations. In this respect, they neglect to recognize many contributions that are reflected in Vicker's insightful work [end note 6], as well as in the Laws themselves.

- *Systems dynamics* (fostered by Jay Forrester, Dennis Meadows, Peter Senge, and others often associated with MIT, i.e., the Massachusetts Institute of Technology, located in Cambridge, Massachusetts).
- *Chaos theory* (arising in small groups in many locations).
- *Adaptive Systems Theory* (predominantly associated with the Santa Fe Institute, but now starting to be associated with many schools of business or management).

The fifth school is the one reflected here:

- The *Structure-Based School* (developed by the author, his colleagues and associates, emphasizing the collaborative, computer-assisted construction of structure of a problematic situation as the key step in beginning to resolve complexity in that situation [end note 7].

Table 1. Schools of thought about complexity

Name of School	Underlying formalism	Where complexity lies
Indifference	None	Unspecified
Systems Dynamics	Ordinary differential equations	In the system
Chaos Theory	Ordinary non-linear differential equations	In the system
Adaptive Systems Theory	Partial differential equations	In the system
Structure-Based	Formal western logic; including set theory, theory of relations, digraph theory, lattice theory, boolean methods, and the algebra of partitions	In the mind (Much of the foundational work is represented by the works of C.S. Peirce, J. Piaget, M. Polanyi, and G. Vickers)

Table 1 summarizes the views of the author about these schools of thought. A key factor in comparing these schools of thought is the concept of 'formalism', i.e., an integrated system of signs having the property of being *uninterpreted* (i.e., *situation-independent*) until associations are made with this system [end note 8].

The vast majority of the proponents of Systems Dynamics, Chaos Theory, and Adaptive Systems Theory hold a common point of view about complexity: that *complexity is an aspect of the systems which they explore*. The differences among the three lie (a) in the particular formalisms which underlie their thinking and (b) in the extent to which metaphors (e.g. 'chaos', or 'adaptive systems') are substituted for specific results flowing from applications of the formalisms.

In contrast, the Structure-Based School holds that complexity finds its locus in the human mind, rather than in some corpus that the human is striving to comprehend [end note 9]. Further, this School strives always to find adequate bases for its assumptions in science and, especially in the thinking of a collection of identified Thought Leaders, who are identified later in this paper.

Interactive Management

If it should prove true that the practice of Interactive Management is consistent with a science of complexity that is set forth, it would be much easier to display a comprehensive system, where the science supports the practice, and results from the practice can be fed back to improve the science. Moreover all of the empirical data from the use of Interactive Management could be brought to bear as an evaluatory resource, and all of the learning that has gone on could potentially be applied to help validate the science.

Still, even assuming the best results in linking a science of complexity to the practice of Interactive Management, one cannot feel thoroughly comfortable because there are certain 'not-said' components that leave the entire conceptual complexity package open to criticism; such openings being found at both ends of the spectrum.

Overviewing the Spectrum of Complexity from Foundations to Results

At one end, one must acknowledge that the quality of what arises from a science is dependent upon an infrastructure that supports the development of the science. If that infrastructure is not adequate to enable the science to be properly conceived, and adequately supported with empirical evidence, that science is rightly open to extensive criticism. At the other end of the spectrum, one must acknowledge that it is not sufficient for an organization merely to apply Interactive Management in an effort to resolve problematic situations. Instead, the organization must provide the local infrastructure to support both (a) the conduct of the Interactive

Management work, and (b) the deployment of the products of that work in such a way that a pattern of vertical linguistic coherence evolves in the organization, allowing the products of the IM work to be understood all the way up and down the corporate or government ladder.

Without such an understanding, value can be lost as quickly as it was gained. Moreover, after the IM work has been completed, infrastructure must be present to support the conduct of whatever other methods or practices are required in order to build on and hopefully maximise the returns from developing the products of IM.

A long conceptual distance is traversed in moving from the infrastructure of science to the local infrastructure of an organization that is working systematically to resolve its problematic situations. Moreover, in order to sustain organizational effectiveness, a dynamic process of role redefinition must take place and must become embedded in the organization, so that top-level managers no longer see themselves as complexity resolvers, but rather as strategic enablers and overseers of the quality of information flow in the organization in a way that is commensurate with the nature of complexity.

Unless the killer assumptions (some of which are discussed above) that prevent the demands of complexity from being met can be dissolved for the using organization, the entire struggle may be for naught in that organization.

EDUCATIONAL PRACTICES APPROPRIATE TO COMPLEXITY: THE CURRICULUM OF COMPLEXITY

The first of five highly condensed patterns to be introduced (Figure 1) is called *The Curriculum of Complexity*. The reader may interpret this pattern as a broad hypothesis, set forth to provide a context for a variety of topics relevant to complexity.

This pattern involves attempts to aggregate earlier research products, then organize them carefully, to try to make the results more easily understood, while emphasizing complexity as the principle theme. The biggest difficulty in doing this is trying to achieve Argyris-type 'framebreaking' [end note 10] (i.e., to dissolve patterns of belief that are not consistent with the laws). If that can be done, then 'remodeling' is a lesser task. Because of the urgency in making this work understood, *The Curriculum of Complexity* has been prepared to serve as an overview for learning this material. The *Curriculum* incorporates four 'Courses':

- The Infrastructure of Science
- A Science of Complexity
- The Work Program of Complexity
- Implementation: Organizations and Complexity

The Infrastructure of Science is a necessary first Course, because without an understanding of the conditions that support the ongoing development and refinement of science, it is almost impossible to explain the *Science of Complexity*. Without going back to foundations, such a science cannot be seen in perspective. Also without that understanding, one cannot really comprehend why the *Work Program* is laid out the way it is, and why organizations have to become aware of the demands of complexity (as inferred from the Laws) in order to provide a work environment that is adequate for working with complexity.

The *Science of Complexity* falls into place if *The Infrastructure of Science* is understood. *The Work Program of Complexity* is readily illustrated by many applications. If the first three Courses are well understood, the organization may take the steps needed to make it possible to carry out *The Work Program of Complexity* repeatedly, on a large scale, for many issues.

A Practitioner Learning Strategy

It is possible for practitioners to learn what is in Courses 3 and 4 without taking any interest in Courses 1 and 2. That is the route that most practitioners have taken in the past. Probably the greatest benefit for practitioners from studying Courses 1 and 2 would be that they gain the understanding to explain why the Interactive Management system is unique; and why other methods that have been and continue to be used

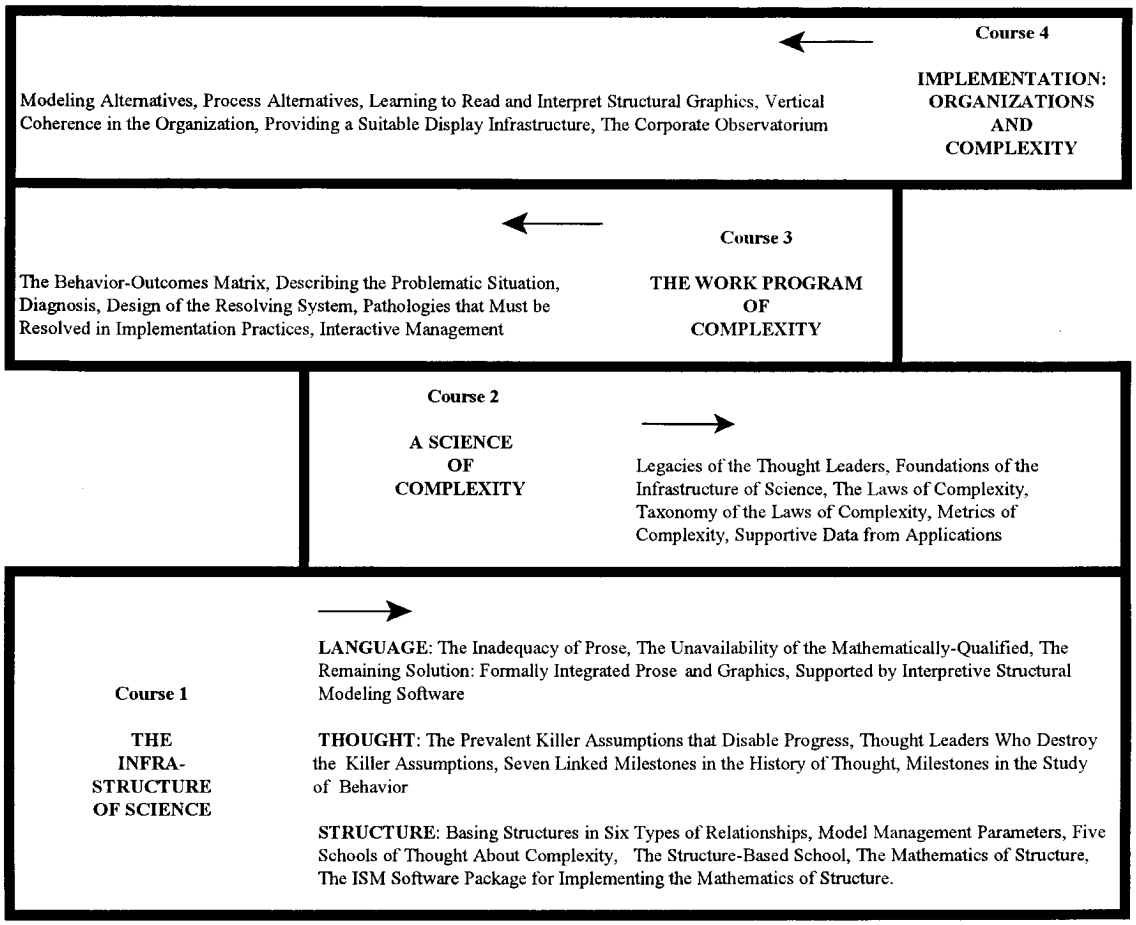

Figure 1. The curriculum of complexity

cannot substitute for the powerful, computer-assisted structuring process called Interpretive Structural Modeling (ISM) [end note 11]. This should help them explain to upper management why IM is needed in the organization. This is believed to be quite difficult, because upper management historically has been called on to manage the complexity, without having the requisite process support. On the one hand, they feel that it is their domain while, on the other hand, they do not know (a) that such support is possible and (b) how to reconceive their role when the support becomes readily available.

The pattern in Figure 1 has provided brief descriptions of these four courses. Now we turn to each of the four areas in turn.

QUALITY CONTROL OF SCIENCE 1: THE INFRASTRUCTURE OF SCIENCE

As was seen in Figure 1, the Infrastructure of Science focuses upon language, thought (including behavior), and structure. The inadequacy of prose alone to represent complexity has been discussed elsewhere [end note 12]. The chosen language of the Structure-Based School is a combined prose–graphics language. This language is defined in *A Glossary of Complexity* [end note 13].

Thought Leaders

In the Structure-Based School, thought is often seen to involve what are called 'Killer

Assumptions' which disable progress. Thought leaders [end note 14] have identified the philosophical basis for destroying those Killer Assumptions. The latter have become prominent because of the lack of recognition of the relevance of certain milestones in the history of thought which are shown in Figure 2. This condensed pattern reflects the point of view that the most intense form of scholarship lies in philosophy. The word 'philosophy' is derived as a conjunction of two Greek words meaning first 'love' and second 'wisdom', so that the term translates into 'love of wisdom'. Only a small percentage of the world's philosophers exemplify that term to the

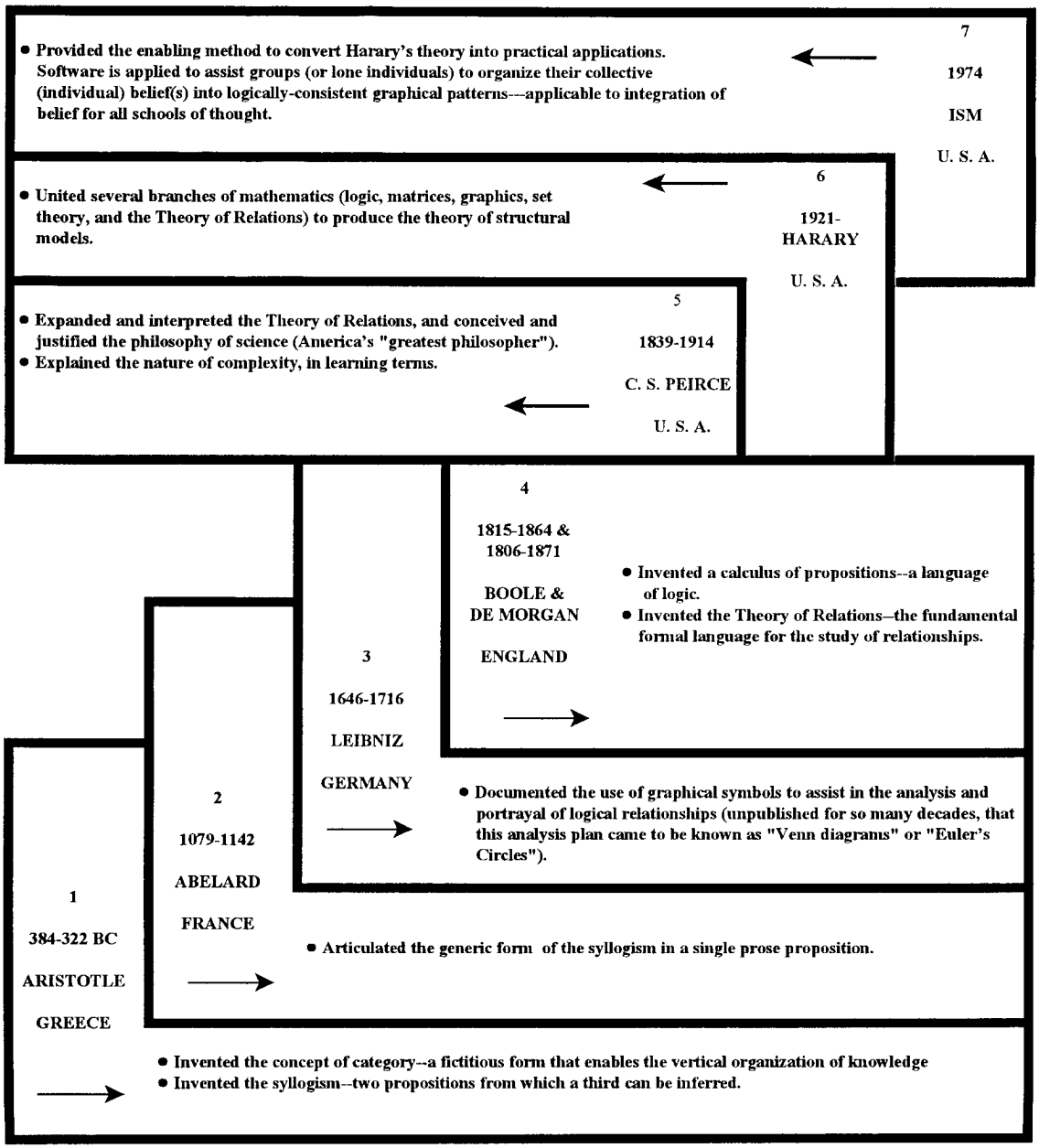

Figure 2. Chronology: seven milestones in the history of thought

fullest. Boxes numbered 1–5 in Figure 2 represent key philosophers who have contributed to the thought component of the Infrastructure of Science. Thought leaders who have contributed heavily to understanding of the infrastructure of science include Peter Abélard, Aristotle, W. Ross Ashby, I.M. Bochenski, George Boole, Kenneth Boulding, Augustus De Morgan, Michel Foucault, J. Willard Gibbs, F.A. Hayek, David Hilbert, Antoine Lavoisier, Harold Lasswell, Gottfried Leibniz, F.S.C. Northrop, Charles Sanders Peirce, Alexander Pope, Geoffrey Vickers, and A.N. Whitehead [end note 14].

Evolution of Thought about Thought

What is seen in Figure 2 is the evolution through time of *thought about thought*. What is portrayed in this evolution is a slow drift toward formalism in expression. Formalism refers to the use of well-defined language as a means of expression. The seven milestones shown here, when carefully examined, reveal a linked pattern of support and enhancement of this slow drift, beginning well over 2000 years ago, and reaching a state of pragmatic utility in the last decade of the twentieth century. In this seventh state, computer support is provided to enable aggregated and integrated human belief to be developed, revealing interpretive patterns to help human beings resolve complexity.

Extensive research supports the pattern shown here, not only in terms of relevant fundamental literature from appropriate disciplines, but also in terms of empirical evidence, found in a wide variety of applications, where today's interpretation of this pattern has been tested and found to be highly effective in serving the needs found in applications.

Behavioral Pathologies

Partly because of the lack of pervasive recognition of the milestones in the history of thought, various behavioral pathologies have taken strong root in organizational cultures. These are identified in Figure 3.

Four milestones in the study of behavior are shown there. Personal (individual) behavior, group behavior, and organizational behavior all suffer from various pathologies that involve unwise assumptions. Individual pathologies propagate into behavior of groups; and group pathologies propagate into the organization. These group pathologies, as the subject of study, foster the definition of laws of complexity that can be empirically discovered within organizations, by observing the performance of the three behavioral categories: personal, group, and organizational. Interactive Management, informed by the 20 Laws of Complexity, offers a comprehensive response to the behavioral pathologies of individuals, groups and organizations. The macro response consists of a rigorous, structured process. The micro response designs into the process openness and flexibility. The carefully planned integration of rigidity and flexibility allows the 20 Laws to be interpreted in process terms, while maintaining consistency with the mini-infrastructure required for creative productivity.

QUALITY CONTROL OF SCIENCE 2: THE SCIENCE OF COMPLEXITY

The science of complexity benefits substantially from *The Infrastructure of Science*. By overtly constructing the language, drawing on the insights from the evolution seen in the chronology of the history of thought, and taking into account the views of the thought leaders that have been identified in the foregoing, it is possible to construct a science of complexity.

Clearly a whole science cannot be presented in this paper, but two aspects of it can be highlighted. First, the Laws themselves, presented in the Appendix, present a significant component of the science. In addition to that, it is now possible to present five Indexes of Complexity that can be quantified, and which have been computed in various applications of Interactive Management to problematic situations [end note 15].

Figure 4 is a condensed pattern that shows the five computable Indexes of Complexity. These stand in a role similar to that of the physical

DOMAIN	CONTRIBUTORS	COMMENTS
4 INTERACTIVE MANAGE-MENT RESPONSE	• Delbecq/ **Generate, Clarify, and Screen Positively** • ISM/ **Structure Beliefs** • Osborne/ **Enable Creativity** • Tuckman/ **Normal Undesigned Sequence** • Bales/ **Behavioral Categories** • Miller/ **Weakthink** • Peirce/ **Let Science Flourish**	Interactive Management (IM) is a system of management that corrects the evils uncovered in the behavioral studies described below. In addition to eliminating the ineffective, resource-wasting process activities, it incorporates positive features replacing bad habits with good ones. It incorporates **Osborne's** ideas on enabling creativity; and the ideas of **Delbecq**, et al, on generating, clarifying, and screening ideas. It eliminates the fruitless components of **Tuckman's** sequence; uses **Bales'** ideas in designing roles for the IM process; recognizes in its design **Miller's** ideas on thought limits, and rests on **Peirce's** concept of science. ISM replaces unorganized speculation with structured thought, developed in a group setting. This leads to unsurpassed group productivity, along the lines of the thought of **Hedberg,** et al.
3 ORGANIZA-TIONAL BEHAVIOR	• Simon/ **Satisficing Approach to Improvement** • Hayek/ **Clanthink in Social Science** • Downs/ **Predictable Behavior of Bureaucrats** • Vickers/ **Linguistic Pollution** • Foucault/ **Susceptibility to Received Doctrine** • M. C. Jackson/ **Fads, Fashion Accessories** • Argyris/**Framebreaking and Remodeling** • Hedberg, et al,/ **Process Installation is Vital** • Alberts/ Cárdenas & Rivas/ **Vertical Coherence in Organizations**	**Simon, Downs, Jackson, and Argyris** argued and reinforced the idea that organizations are not managed by reason, but by all manner of unsupportable behavior, ranging from unquestioning acceptance of unjustified concepts to major susceptibility to fads of the day. Also evinced are the undue influences of "prestigious" institutions that promote faddish ideas widely in order to help assure survival of their organizations. **Foucault, Hayek, and Vickers** argued and reinforced the idea that vast domains of "knowledge" are not supportable by evidence, and that linguistic pollution is rampant in the so-called "scholarly" organizations. **Alberts** and the team **of Cárdenas and Rivas** demonstrated "vertical linguistic incoherence" in organizations by showing what is required to avoid that major difficulty. **Hedburg, et al**, insisted that installation of high-quality processes in organizations is the key to their effective performance.
2 GROUP BEHAVIOR	• Tuckman/ **Group Evolution Sequence** • Janis/ Allison/ Teigen and Warfield, **Groupthink**, etc. • Warfield/ **Clanthink** • Warfield/ **Spreadthink**	**Tuckman** showed that groups typically follow a developmental sequence: forming, storming, norming, and performing. **Janis** defined Groupthink--a pathology in group behavior. **Allison and Teigen** furnished case studies to support **Janis'** ideas. **Warfield** showed that when complexity is involved, groups exhibit Clanthink and Spreadthink, both of which defeat efforts to resolve issues.
1 PERSONAL BEHAVIOR	• Osborne/ **Don't Stifle Creativity** • Bales/ **Categorize Personal Behavior** • Miller/ Simon/ Warfield/**Short-Term Memory Limits** • Yntema & Mueser/ **Cross-Cut ThinkingLimitations**	**Osborne** showed that individuals are quick to find something wrong with any creative suggestion that is offered. **Bales** showed that personal behavior can be categorized into task-oriented and emotional categories allowing personal profile development. **Yntema & Mueser** showed that individuals lack good ability to assess across multiple concepts. **Miller and Simon** showed that individuals have severe limitations on short term memory. **Warfield** showed that these limitations are more severe than first thought.

Figure 3. Milestones in the study of behavioural pathologies

standards that lend integrity to the physical sciences. With the ready possibility of computing and comparing values of these indexes, and referring them back to the seven milestones in the history of thought, and also to the milestones in the study of human behavior, a type of closure is obtained. This type of closure should be viewed as compelling in terms of framebreaking and remodeling of human enterprises; and in the reconstruction of human knowledge, as recommended in the works of Michel Foucault and others [end notes 10 and 16].

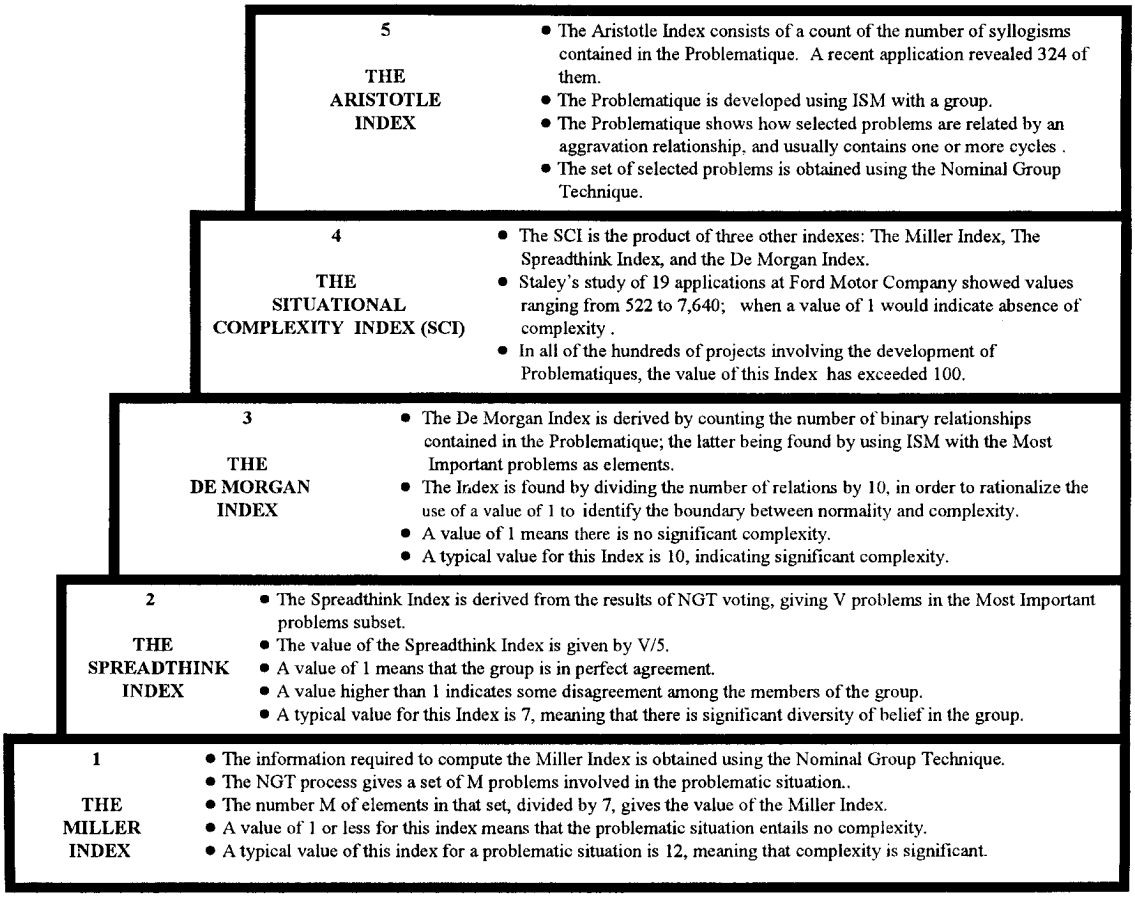

Figure 4. Five indexes of complexity

APPLICATIONS 1: THE WORK PROGRAM OF COMPLEXITY

The Work Program of Complexity has been undergoing empirical testing in many applications for many years. Its application has provided a variety of discoveries that have gone into the formation of the Laws. The present status of the Work Program can be indicated by noting the variety of organizations that are now active in carrying it out, applying Interactive Management as the sole or as a major component of what is being done [end note 17].

The previously shown condensed patterns, and the knowledge stemming from the laws, allows the development of the condensed pattern shown in Figure 5, which represents the *Work Program of Complexity*. This is the master action plan, which begins with the use of Interactive Management, primarily to carry out the first and third components of the Work Program: namely *Description* and *Design*. The second component, *Diagnosis*, is based on the *Description*, and normally does not require the kind of group activity that is essential to the first and third components. The fourth and final component, *Implementation*, can benefit greatly if the organization establishes the necessary communications infrastructure that is recommended: the Corporate Observatorium [end note 18].

The Behavior-Outcomes Matrix

The connections between the *Work Program of Complexity* and the Laws of Complexity are of

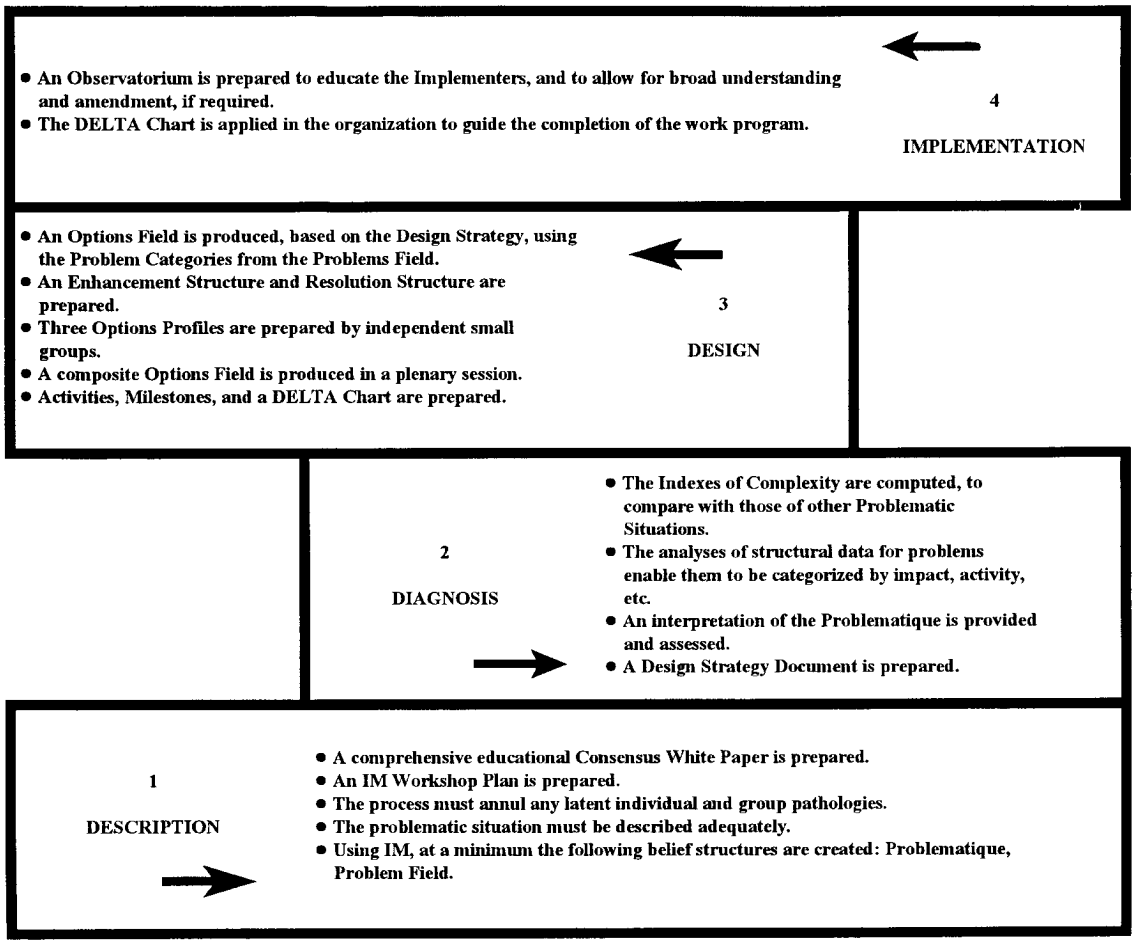

Figure 5. The work program of complexity

primary importance in assessing the applicability of the science itself as well as the implementing system called Interactive Management. Unless clear and useful connections exist and are understood, once again the possibility of irrelevance arises. An appropriate means for showing these connections could be to construct a matrix that would show, for each component of the Work Program of Complexity, which Laws are particularly relevant, and in what way.

Such a matrix is presented in the Appendix (see Figure 6). It is called the Behavior-Outcomes Matrix. Not only does it show which Laws are particularly relevant to which component of the Work Program of Complexity, but it also focuses the relevance upon the particular behavioral component involved (e.g., individual, group, organization, process).

APPLICATIONS 2: TAXONOMY OF THE LAWS OF COMPLEXITY

Because of the growing number of Laws of Complexity, given in detail in the Appendix, it has become timely to develop a taxonomy of the Laws, so that they can be discussed in the aggregate in order to help interpret their impact. Heading this taxonomy is the 'Law Taxonomy Triad': {*Behavior, Media, Mathematical*}. The specifics of the Taxonomy appear in the Appendix. (It is shown there that some of the Laws can

BEHAVIOR	OUTCOMES: DESCRIPTION	DIAGNOSIS	PRESCRIPTION (DESIGN)	IMPLEMENTATION
PROCESS	■ Limits ■ Triadic Necessity & Sufficiency ■ Universal Priors	■ Success & Failure ■ Universal Priors		■ Gradation ■ Validation
INDIVIDUAL	■ Limits ■ Triadic Compatibility ■ Small Displays		■ Requisite Parsimony ■ Requisite Saliency	
GROUP	■ Limits ■ Uncorrelated Extremes	■ Inherent Conflict ■ Structural Under-conceptualization ■ Diverse Beliefs	■ Requisite Variety ■ Induced Groupthink	
ORGANIZATIONAL	■ Limits ■ Organizational Linguistics ■ Vertical Incoherence	■ Forced Substitution ■ Precluded Resolution ■ Vertical Incoherence		

Showing how Laws of Complexity relate strongly to combinations of behavior and outcome (Understanding The *Work Program of Complexity*).

Figure 6. Behaviour–outcomes matrix

reasonably be placed in more than one category.) The following categories and subcategories have been chosen.

Type A: Behavior (70% of the Laws in Three Subcategories Involving Human Behavior)

- *Habitual Behavior:* Constraints that human beings have imposed upon themselves, almost without thinking, evolved through prolonged activity.
- *Physiological Behavior:* Constraints on human behavior imposed by their physiology.
- *Organizational Behavior:* Aspects of human behavior that inhere from their participation in organizations.

Type B: Media (10% of the Laws in One Category Involving Communication Media)

- *Linguistics of Communication:* Matters that affect media of human communication, including various aspects of human written or oral interactions.

Type C: Mathematical (30% of the Laws in One Category Involving Mathematical Operations)

- *Mathematical Operations:* Laws arrived at by mathematical operations, whether theoretical or empirically based, or both.

Distribution of the Laws Among the Categories

As is seen in the Appendix, 70% of the Laws fall into the *Behavioral* category; while 30% fall into *Mathematical* and 10% fall into *Media*. (The reader is reminded that a few fall into more than one category, which is why the total percentages exceed 100.) Since none of the Laws is based in the so-called 'hard sciences', it is reasonably clear why technologists are unlikely to appreciate these Laws, and are likely to make arbitrary judgments (often efficiency-based) that encroach

on the domain of these Laws. This should also make clear why, in discussing the five Schools of Thought about Complexity, the three that relate to differential equations have relatively little in common with the Structure-Based School. The latter school, drawing its origins largely from the Infrastructure of Science, recognizes that human beings create structure, whether they are scientists or not, that they do so with the aid of language, that language is of behavioral origin, and that behavior is a social phenomenon not readily dealt with in terms of calculus or calculus-based formalisms.

ENABLING CONDITIONS FOR EFFECTIVE ORGANIZATIONAL PRACTICE: THE ORGANIZATION'S INFRASTRUCTURE

The Laws of Complexity offer science that is applicable in organizations. This may best be seen by noting that every single Law can be considered as an 'IF–THEN' construction. If this seems a bit novel, one might momentarily retreat to the laws of physics. Though these laws are often formulated as algorithms, essentially all of them embrace certain preconditions which, if not met, render the algorithm irrelevant. It should not be surprising that a similar situation holds for the Laws of Complexity.

The Positive Construction: Orienting the Laws Toward Success in Organizations

Taking any one of the Laws, the 'IF' and the 'THEN' can be extracted. Consider the first-listed Law, The Law of Triadic Compatibility, from Appendix A as an example. The Law speaks about compatibility of the human mind to explore interactions among a set of elements. IF the number involved is three or less, or IF the total number of elements and interactions is seven or less, THEN the mind is compatible. The Positive Construction from this Law is clear: if the individual can manage to keep the numbers down, success in reasoning is a likely outcome.

The Negative Construction: Orienting the Laws Toward Failure in Organizations

As mentioned before, the 'IF' and the 'THEN' can be extracted from each Law. Considering again the first-listed Law, the negative construction tell us that attempts to work simultaneously with more than the specified numbers are very likely to fail. The Negative Construction is clear: avoid exceeding the threshold of mental effectiveness.

The Yin and the Yang

The dual nature of all of the laws, i.e., the positive and negative constructions, tells us on the one hand the conditions under which the organization need not fear the impact of the Law; while on the other hand telling us that failure is very, very likely if the organization does not control the conditions under which the Law can operate.

Keeping in mind that *all* the Laws can be operating concurrently within a given context, it should be clear that what is required is a master process that has designed into its operations the conditions required to prevent *any* of the Negative Constructions from occurring. This is done by controlling the 'IF'. In other words, the design disables the 'IF' component of the Law and, thereby, prevents the 'THEN' component from having any negative impact. That is, in essence, the reason that Interactive Management is successful in organizations when applied to work with complexity.

The Corporate Observatorium

Interactive Management, in the absence of an adequate corporate infrastructure, can only be marginally valuable. No matter how high in quality the products of the application of Interactive Management may be, if they are not disseminated to, understood by, and put into practice by those organizational employees who have the talent and know-how to make the results effective, the organization cannot reap the benefits of the work. That is why the Corporate

Observatorium has been conceived as the means of making those good things happen.

CONCLUSIONS

Reductionism and systems thinking can coexist, but not in harmony. Wherever reductionism is successful, it will be found that prior systems thinking enabled a problematic situation to be sorted into relatively independent dimensional components. Today such components are applied in organizations both in management and in technology development. But they cannot be substituted for an effective process for working with complexity.

The Laws of Complexity stand not as a set of separate ideas to be invoked piecemeal; rather they are deployed like a collection of highly armed armadas attacking organizations individually and collectively, as a warlike body. Unless the variety in this armada is countered dimension-by-dimension by a process founded in integrated science, the armada will carry the day.

When applied in organizations, the Laws should be dually recognized: the 'IF' portion of each Law should be suppressed with respect to its negative implications; and enhanced with respect to its positive implications. In the hurly-burly of practice, such an approach cannot be spontaneous, but must be worked out ahead of time. Interactive Management has been constructed to fill that description, being founded within the budding science of complexity offered here. Moreover the quality of that science has been referred both to a long history of scholarly development, as well as immediate means of measuring complexity in particular problematic situations. Finally a growing body of empirical evidence in practice supports the views presented here.

FUTURE RESEARCH

It is inherent in science that it requires a dedicated body of scholars striving constantly to detect its flaws, while simultaneously working to enhance its strengths. This is the general tone that future research should take in the domain of complexity. More specifically, every idea offered here can be challenged and put to the test. At present weaknesses are found in infrastructure at both ends of the spectrum of human activity: the infrastructure of science, and the infrastructure of practice. Especially now, it is feasible to undertake infrastructural studies in organizations that strive to benefit from an understanding of the Laws of Complexity. These studies should focus on large-scale learning, and on constant updating of large structures of information. Finally, the university, as a primary beacon for learning, should take advantage of its unique position in society to champion what is presented here in its educational programs.

END NOTES

[1] Ackoff, R.L. (1995). 'Whole-ing' the parts and righting the wrongs. *Systems Research* **12**(1), 43–46. In this paper, Ackoff calls attention to a large number of methods or tools that have been advanced to assist organizations, and suggests that they are not broadly effective. This may well be because organizations try to apply them to resolve complexity, in spite of the fact that there is no adequate logic platform showing that they are minimally adequate for that purpose.

[2] Ketner, K.L. (1973). *An Emendation of R.G. Collingwood's Doctrine of Absolute Presuppositions*, Graduate Studies Number 4, Texas Tech Press, Lubbock, TX. This work includes several other valuable references to the foundations of presuppositions, supplementing C.S. Peirce's well-known taxonomy of how belief is fixed.

[3] Warfield, J.N., and Cárdenas, A.R. (1994). *A Handbook of Interactive Management*, Iowa State University Press, Ames, IA. This book is aimed specifically at resolving complexity. The book describes in great variety a system of management intended to be applied intermittently in organizations just to resolve complexity in those organizations.

[4] Warfield, J.N. (1996). Five schools of thought about complexity: implications for design and process science. In Tanik, M.M. *et al.*, (eds), *Integrated Design and Process Technology* (IDPT, Vol. 2), Proc. Society for Design and Process Science, Austin, TX, pp. 389–394. This paper identifies and describes the five schools of thought, and emphasizes the weak foundations on which four of them rest.

[5] Hayek, F.A. (1955). *The Counter-Revolution of Science: Studies on the Abuse of Reason*, Free Press, New York. In this masterpiece, Hayek documents in great detail the onset of positivism in France, and its baleful application in spawning totalitarian regimes. He describes the rise of 'scientism', an imposter in the clothes of science, and unveils the emptiness of the underlying assumptions that support positivism. Some readers might mistakenly think that the Structure-Based School of Thought is a positivistic school. Nothing could be more wrong. To understand fully the key distinctions, it would be well to read several books that collectively offer a thorough philosophical basis for the Structure-Based School. First, one could develop an understanding of Charles Sanders Peirce's views on formal logic. Peirce, in the top rank of the world's logicians, saw the application of formal logic as a means of learning, i.e., constructing hypotheses for evaluation, as opposed to a formula for making final choices. He felt that formal logic was one of three 'normative sciences', the other two being aesthetics and ethics. In his frame of thought, at the deepest level of individual self-governance lies aesthetics, the final arbiter, operating ineffably through the senses. At the next higher level of individual self-governance lies ethics, operating ineffably through the senses under the powerful influence of aesthetics. Just above the level of ethics lies formal logic; the uniquely powerful system of reasoning that informs the senses, having the status of a normative science, because it embodies the love of truth in its operating purposes and consequences. Recent views on Peirce's normative sciences come from the late Potter, V. (1996). *Peirce's Philosophical Perspectives*, Fordham University Press, New York.

The importance of integrating the powers of the senses with the powers of reasoning has also been given a modern treatment in Salk, J. (1985). *Anatomy of Reality: Merging of Intuition and Reason*, Praeger, New York (originally published by Columbia University Press). To bring these lines of mutually reinforcing thought into one context, the reader can turn to Vickers, G. (1983). *Human Systems are Different*, Harper & Row, London.

[6] A thorough airing of responsibility and its connection to organizations is found by reading several books by Vickers, G. (1983). *Human Systems are Different*, Harper & Row, London; (1965, 1983). *The Art of Judgment: A Study of Policy Making*, Harper & Row, London; (original 1965, Chapman & Hall); (1980). *Responsibility: Its Sources and Limits*, Intersystems, Seaside, CA.

[7] The Structure-Based School has revealed three central findings about *problematic situations* that arise, typically in organizations:

- There exists *a plethora of component problems* in the problematic situation (hence, expressions such as 'begin by defining the problem' and 'problem solution' are both empty and misleading).
- There exists *widespread difference of belief* among well-informed individuals about what is most important in a situation (a phenomenon identified as 'Spreadthink').
- A *large number of problem interdependencies* are seen among the (usually large) number of problems that arise from the minds of the observers of a situation.

[8] Flew, A. (1984). *A Dictionary of Philosophy* (2nd edn), St Martin's Press, New York, pp. 123–124. From this widely acknowledged work, Anthony Flew has defined the important term 'formalism', which is a central concept of science, its relative obscurity notwithstanding:

- *Formalism:* 1. (mathematics) A view pioneered by D. Hilbert (1862–1943) and his followers, in which it was claimed that the only foundation necessary for mathematics is its formalization and the proof that the system produced is consistent. Numbers (and formulae and proofs) were regarded merely as sequences of strokes, not as objects denoted by such strokes.

[9] *The Nature of Complexity*. In his famous paper published in 1878, entitled 'How to Make our Ideas Clear', Charles Sanders Peirce talked about false distinctions that are sometimes made in discussing beliefs. He wrote the following:

> One singular deception of this sort, which often occurs, is to mistake the sensation produced by our own unclearness of thought for a character of the object we are thinking. Instead of perceiving that the obscurity is purely subjective, we fancy that we contemplate a quality of the object which is essentially mysterious ...
>
> ... So long as this deception lasts, it obviously puts an impassable barrier in the way of perspicuous thinking; so that it equally interests the opponents of rational thought to perpetuate it, and its adherents to guard against it.

We see here Peirce's fundamental view that human behavior strives to focus complexity away from the person and onto whatever the person is unable to comprehend, be it tangible or not. Furthermore he alerts us to the 'impassable barrier' that comes when that mode of behavior dominates what goes on.

[10] Argyris, C. (1982). *Reasoning, Learning, and Action: Individual and Organizational*, Jossey-Bass, San Francisco. C. Argyris, in his studies of behavior in organizations, discusses 'framebreaking' and 'remodeling' as two key actions involved in organizational reform. These terms incorporate ideas of false assumptions that have been integrated into framed patterns for decision-making; and the necessity to break these frames and remodel by building new framed patterns that incorporate higher-quality assumptions, or better still established scientific knowledge.

Framebreaking is implicit in M. Foucault's insistence on upgrading knowledge: 'We must renounce all those themes whose function is to ensure the infinite continuity of discourse and its secret presence to itself in the interplay of a constantly recurring absence [the ''not-said''].'

Remodeling is implicit in M. Foucault's: 'The problem ... is no longer one of lasting foundations, but one of transformations that serve as new foundations, the rebuilding of foundations.'

The idea embodied here was stated by I. Kant in his definition: 'Enlightenment is man's release from his self-imposed tutelage.'

[11] Interpretive Structural Modeling (ISM) is unique because it instruments (i.e., provides an enabling mechanism for) the formal logic that has evolved over more than 2000 years, finally attaining a state of pragmatic utility with the availability of software that supports this process. This process is described in Warfield, J.N. (1976). *Social Systems: Planning, Policy, and Complexity*, Wiley, New York. A version of the ISM software can be downloaded without charge, along with a user's guide, from the Web site identified in end note 13.

[12] Warfield, J.N. (1993). *Procrustes is Alive and Well and Teaching Composition in the English Department*, IASIS, Fairfax, VA. This report, available from the author, shows clearly the structural constraints involved in the use of prose, and explains why these constraints are not compatible with the representational requirements of complexity.

[13] Recent IASIS publications are available that add considerable depth to these ideas. They are typically available at cost of production and shipping. Titles can be seen at this Web site: http://www.gmu.edu/departments/t-iasis. One of those publications by J.N. Warfield is entitled *A Prose–Graphics Glossary of Complexity*.

[14] Thought Leaders identified here, and the concepts that they have made available to this work, can be seen in Appendix 1 of *The Wandwaver Solution*, which can be seen at the Web site identified in end note 13.

[15] Staley, S.M. (1995). Complexity measurement of systems designs. In Ertas, A., Ramamoorthy, C., Tanik, M., Esat, I., Veniali, F. and Bendiab, T. (eds), *Integrated Design and Process Technology*, in Conference Proceedings, Society for Design and Process Science, December, pp. 153–161. This publication summarizes nicely several of the Indexes of Complexity, and provides tabular data from a series of Interactive Management Workshops carried out at the Ford Motor Company in Dearborn, MI, and in the UK.

[16] Foucault, M. (1993). (A.M. Sheridan Smith, translator from the French) *The Archaeology of Knowledge and the Discourse on Language*, Barnes & Noble, New York (earlier publication in 1969 and 1971). This work must be read for its highly articulate expression of where thought goes astray today, because it is based in foundations that are unsustainable, and which need to be reconstructed, as discussed in end note 9.

[17] The empirically sensitive reader can go further in exploring what goes on in the practice of Interactive Management (IM). Table 2 identifies individuals and locations that are presently active in this area. (The author will supply more details to questioners, if requested.)

[18] Warfield, J.N. (1996b). The corporate observatorium: sustaining management communication and continuity in an age of complexity. In Tanik, M.M. *et al.*, (eds), *Integrated Design and Process Technology* (IDPT, Vol. 2), Proc. Society for Design and Process Science, Austin, TX, pp. 169–172.

This paper discusses the infrastructural requirements of large organizations that hope to have vertical linguistic coherence in their internal communications. By constructing an observatorium built from the products of applications of Interactive Management, both overview and details of organizational future activities can be made visible to everyone, benefiting from the creative use of real estate.

APPENDIX: BRIEFS OF THE LAWS OF COMPLEXITY

This Appendix presents Briefs for each of the Laws of Complexity. The principal connections between the Laws of Complexity and the Work Program of Complexity are shown in Figure 6, the Behavior–Outcomes Matrix (BOM). The contents of a matrix cell are the names of the Laws that are particularly relevant to the intersection of a component from the Behavioral Menu and a component of the Work Program of Complexity.

In addition to the study of which Laws relate to which activities, shown in Figure 6, it is also appropriate to recognize that an understanding of some of the Laws will make it easier to understand other of the Laws. This idea plays a role in constructing a learning sequence. In presenting the Briefs for the Laws, a particular learning sequence has been developed which, it is hoped, will make it easier to develop an integrated perspective on them. This sequence appears in Figure 7. Because this document is prepared for persons who are unfamiliar with the Laws, no attempt will be made at this point to justify the learning pattern shown.

Taxonomy of the Laws of Complexity

As mentioned earlier, the 20 Laws have been placed into categories. Table 3 shows the categories to which the various Laws have been assigned.

The Revolving Door to Enlightenment

Omar Khayyam (mathematician and astronomer, 1048–1122), speaking through the voice of Edward Fitzgerald (1809–1883), vented his frustration stemming from his attempts to get understanding, as follows:

> Myself when young did eagerly frequent
> Doctor and Saint, and heard great argument

Table 2. Practitioner organizations

Organization and contact(s)	Origins and/or notes on activities
Centre for Interactive Management India (CIMI) Dr Surinder K. Batra	Dr Batra visited George Mason University while employed by Tata Ltd, and spent six weeks observing IM in action. After returning to India, he completed his doctoral degree, completed his employment with Tata Consulting Services, and started his own business as listed above. He has worked with a wide variety of clients on several continents
Complexity Solutions Limited (CSL) Bill Rodger, North America Michael McMaster, Europe	Complexity Solutions Limited (CSL) was set up in 1997. It provides management consulting services to clients in government and industry, and licenses of its processes to consultants and corporations. CSL provides software technology developed by Desyma Decision Technologies Inc. to consultants and corporations interested in acquiring capability in the application of IM to the resolution of complex issues. CSL licenses the software, trains facilitators in its use and provides coaching on the use of IM to specific situations and to building a consulting practice. The company has licensed consultants specializing in the petrochemical industry, medical service provider networks and major organization change efforts in the UK and USA
CWA Ltd Dr Alexander Christakis, Dr Alex N. Pattakos	CWA Ltd has developed the CogniScope™ system. It requires five ingredients for its work: (1) Community of Stakeholders; (2) CogniScope™ Team; (3) CogniScope© software for recording ideas and meanings; (4) Consensus Methods, selected from the universe of available problem-solving and design methods, on the basis of technical and behavioral criteria for productive dialog leading to action; and (5) A Collaborative Facility which promotes the comfort and contributions of the participants as stakeholders, and has the capability to display visually the observations constructed through the dialog. CWA has had a large variety of clients, many from the pharmaceutical industries. It played a major role in assisting the US Food and Drug Administration in receiving the 'Innovations in Government Award', a prized award that is comparable to the Deming Award in terms of its significance. CWA boasts a long history of IM work, much of which took place before CWA started as a business. This includes work with American Indian tribes, US Forest Service, United Fund, and others. At present CWA is working in Greece to train high-level administrators in the government of Greece
Desyma Decision Technologies Inc. Bill Rodger	Desyma was set up in 1989 to develop software used in IM. The product developed, SYNERGISTIC SOLUTIONS, has been used by Desyma since 1990 to provide management consulting services to clients in Canada, the USA and Europe. The current version being used is the second-generation product and is based on the experience acquired by Desyma in applying IM in a variety of industry, government, academic and non-profit organizations. Desyma is currently completing the development of a new, third-generation product which will add additional functionality needed by both the process facilitators and process participants. New capabilities will include multiple site support for electronic conferencing. Desyma has a VAR agreement with Complexity Solutions Limited for the marketing of SYNERGISTIC SOLUTIONS worldwide
ITESM Campus Monterrey Professor Roxana Cárdenas Dept. Systems Engineering, Instituto Tecnologico de Monterrey	Teaching and consulting services in IM have been provided at ITESM Campus Monterrey for about a decade. This includes consulting with industrial firms, carrying out projects related to government, teaching satellite classes in generic design science, doing short courses for other branch campuses of ITESM, and collaborating with Professor John Warfield of George Mason University on many projects. These included co-author of *The Handbook of Interactive Management*, facilitation at Ford Motor Company, facilitation at the CSIR in Accra, Ghana; and facilitation at George Mason University in short courses offered there. Roxana has a number of experienced collaborators at ITESM Monterrey, including Carmen Moréno, who has assisted in conducting defense systems management workshops in the USA, as well as facilitating a variety of workshops in Mexico
The Jeffrey Group Carol Jeffrey	The Jeffrey Group has conducted Interactive Management work related to reorganization of the science establishment in Ghana, and to demobilization and reconstruction in Liberia, as well as other projects of considerable variety

Table 2 continued over page

Table 2. Continued

Organization and contact(s)	Origins and/or notes on activities
ITESM Campus León Reynaldo Treviño Centro de Estudios Strategicos	In 1997, this group facilitated IM with people of different sectors and with functionaries of the municipal administrations of four Mexican counties: San Diego de la Union, Purisima del Rincon, Romita and Tierra Blanca. We examined the general problematique of those counties, including their rural communities, and got deep into the analysis of their economic sectors, which are different in each case, and also into the analysis of their critical factors, like education, health, jobs, communitarian services, public security, public administration, water resources–management–distribution, ecology, etc. The diagnoses resulting from those sessions were used for designing collaborative actions in each case, and these were later systematized under general strategies which were also prioritized to give them an order in the Integral Municipal Development Plan for each one of the counties. The main products were: (1) a general and specific diagnosis, which was complemented with statistical data and its interpretation for each one of the counties; and (2) their Municipal Development Plan, 1998–2002, according to five big categories: Economic Development, Social Development, Educational Transformation, Conditions of Laws and Regulations, and Good Governmental Practices. These Plans also contain General Objectives to be achieved for each big category, and suggested performance measures for each single action to be implemented Now this group is working in planning the Socioeconomic Development for the most important county in Guanajuato in regard to economic activities and number of inhabitants, i.e., León, and soon will begin the same kind of task as described previously, for Comonfort, Penjamo, Moroleon, Allende, and perhaps also for Yuriria, Cortazar, Tarandacuao and Huanimaro. This will be a huge work, probably requiring more than 80 IM workshops, just to provide the basis for elaborating their plans, 1998–2003. This link of ITESM to the communities is dictated by the ITESM Mission
Professor Benjamin Broome, George Mason University	Professor Broome can be contacted through the George Mason University home page at http://www.gmu.edu/departments He has about a decade of experience with IM applications. In recent years he has facilitated IM workshops at Ford Motor Company, and in Cyprus, where he has worked for over two years on a Fulbright Award to help bring peace to the warring factions on Cyprus. As a result of that work he is now being asked to provide more and varied services related to IM, both in the USA and in Europe
Phrontis Limited Tony Gill	Phrontis was set up in April 1994. It has systems thinking, in the widest sense, at the core of its services in consultancy, training, facilitation and management resources. Clients come from a number of industries, notably the Oil & Gas and Telecoms industries. A recent assignment involved risk assessment and transparency in the Swedish Nuclear Industry using a combination of systems thinking approaches. Since Tony participated in a workshop on IM led by John Warfield during 1995, Phrontis has been involved in the planning and delivery of IM workshops for NatWest Bank and British Telecom. We see IM as an important management tool to help clients structure intractable problems involving multiple stakeholders. We have done an IM Workshop with NatWest Bank as part of a research project in July 1996 and another in November 1996 with Bill Rodger's involvement for British Telecom European Marketing Group in Brussels. Phrontis has a web page devoted to IM: http://www.phrontis.com/facilim.htm

About it and about: but evermore
Came out by that same door where in I went.

The late contemporary French philosopher and chairman of the history of systems of thought at the Collège de France, Michel Foucault (1926–1984), in his masterpiece on the 'archaeology of knowledge', believed (as described by D.W. Harding)

> that our own current intellectual life and systems of thought are built on assumptions

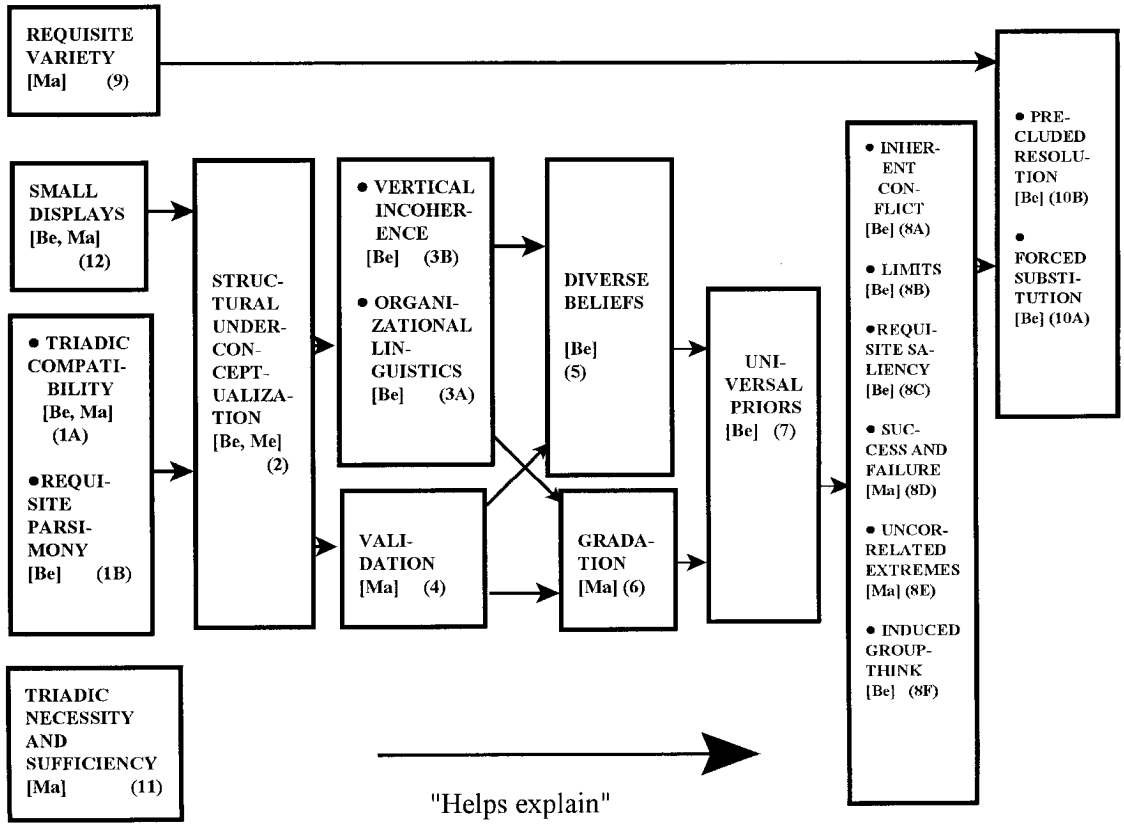

Figure 7. Interactions in interpreting laws of complexity

profoundly taken for granted and not normally exposed to conscious inspection, and yet likely in time ... to be discarded.

In amplifying that view, Foucault states that:

The manifest discourse, therefore, is really no more than the representative presence of what it does not say; and this 'not-said' is a hollow that undermines from within all that is said.

It is none too early to try to begin to correct the shortcomings in our knowledge that stem from bad ('not-said') assumptions, uncritically accepted and propagated, especially in academia. Too much is at stake. Yet, such acceptance seemingly continues its relentless advance, compounded by technologies that typically show little friendliness to their users.

The 20 Laws to be described are intended to be responsive to Omar's complaint.

In this document, the Laws of Complexity that have been discovered to date are presented in the form of 'Briefs'. A Brief is given for each, showing the name of the Law, its origins, references to relevant literature, the statement of the Law, and its interpretation. The list of references for the Briefs appears at the end of the set of Briefs.

There is a dual logic involved in this arrangement. From one point of view, the brief of the Law should be given before it is applied to particular situations. From another point of view, application of the Law to a specific situation sheds light on how to perceive it when it is formally presented.

As presented here, the Laws appear in a specific learning sequence that is correlated with Figure 7. This sequence is believed to support efforts to learn the set of Laws. Because Figure 7 is not a linear graphic, a linear learning

Table 3. Categories of the laws of complexity

Law of		Behaviorally based (70%)			Media-Based (10%)	Mathematically based (30%)
		Habitual	Physiological	Organizational		
1A	Triadic Compatibility		●			●
1B	Requisite Parsimony		●			
2	Structural Underconceptualization	●	●		●	
3A	Organizational Linguistics			●		
3B	Vertical Incoherence			●		
4	Validation					●
5	Diverse Beliefs	●				
6	Gradation					●
7	Universal Priors	●				
8A	Inherent Conflict	●				
8B	Limits		●			
8C	Requisite Saliency	●	●			
8D	Success and Failure					●
8E	Uncorrelated Extremes					●
8F	Induced Groupthink	●		●		
9	Requisite Variety					●
10A	Forced Substitution			●		
10B	Precluded Resolution			●		
11	Triadic Necessity and Sufficiency					●
12	Small Displays	●			●	

sequence in which each Law is studied once in turn is not appropriate for learning the Laws.

Brief 1A: The Law of Triadic Compatibility

Origin(s) of Law: Empirical, (Miller, Simon); Mathematical [Applied Lattice Theory], (Warfield).

References: Miller (1956), Simon (1974), Warfield (1988).

Statement of law: *The human mind is compatible with the demand to explore interactions among a set of three elements, because it can recall and operate with seven concepts, these being the three elements and their four combinations; but compatibility cannot be presumed for a set that both has four members and for which those members interact.*

Interpretation of law: This Law expresses both a human limitation and a human capability. The limitation suggests that human beings cannot process interrelationships among sets of factors, issues, objects, or ideas in general, if more than three components are involved. The reason set forth is that the mind is incapable of recalling into its short-term memory more than about seven items. (A set comprised of three elements and the four interacting combinations of them will consist of seven members.)

A way to show respect for this limitation is to determine that whenever decisions are to be made that can benefit from awareness of interactions, it will be advisable to choose and apply a strategy that recognizes the impact of this limitation.

This limitation should also persuade individuals that intuitive decision-making, carried out without careful analysis, is likely to produce bad decisions and bad outcomes when complexity is present.

The capability that allows us to process interrelationships among three factors — issues, objects, or ideas — should encourage us to begin to develop a facility for working with sets of three items. More specifically, it would be advisable to build up a repertoire of sets of three items that are representative of decision-making situations, and develop skill at working with these sets.

It might be well to remember that many situations in life have been approached as though

there were a dichotomy involved. Instead of allowing our thinking to be limited to dichotomies, we should be encouraged to move to trichotomies as a way of becoming more flexible in thought and action, wherever appropriate.

We may also be persuaded that documentation is much more valuable than might be thought, especially if the documentation takes the form of representing systems of interactions involving more than three interacting members.

When we have developed patterns of interrelationships as documentation, we may work to develop the skill of reviewing and amending such patterns. Moreover, we may begin to see merit in group development of interrelationship patterns, since there is little in the capability to work with three items that suggests an overwhelming power of a single individual to construct patterns of interrelationship that are representative of actual conditions or systems, or of contemplated conditions or systems.

The limitation to interactions among three items suggests a very serious limitation on creative ability as might be reflected in design of complex systems. Ad hoc designs, arrived at in ordinary conversational modes (as, for example, in governmental bodies or committees) might be looked upon as unlikely to be of high quality, and likely to produce bad outcomes.

Brief 1B: The Law of Requisite Parsimony

Origin(s) of law: This law is based on the dynamics of interpreting and learning implied by the Law of Triadic Compatibility. The Law is prescriptive, with the aim of allowing enough time for sequentially presented information to be interpreted in terms of the interactions, and to allow enough listening time to help ensure that the information is remembered.

References: Miller (1956), Simon (1974), Warfield (1988).

Statement of law: *Every individual's short-term brain activity lends itself to dealing simultaneously with approximately seven items (a number that is reached with three basic items and four of their joint interactions) [see the Law of Triadic Compatibility]. Attempts to go beyond this scope of reasoning are met with physiological and psychological Limits that prelude sound reasoning. For a given designer, there is some number K_d that is characteristic of that designer which typically is chosen from the set [5, 6, 7, 8, 9] that represents the Limit of that designer's short-term idea-processing capability. If a design methodology requires a designer to cope intellectually at any one time with some number of concepts K_c, then*

(i) *If $K_c < K_d$, the designer is* underburdened, *being uninfluenced by the Law of Requisite Parsimony, since the designer is operating in a Situation that exhibits the Requisite Parsimony, through regulation of the rate of flow of information to the designer as the designer engages in the design process.*

(ii) *If $K_c = K_d$, the designer is* operating at the limit *of reasoning capability.*

(iii) *If $K_c > K_d$, the designer is* overburdened *and no reliance can be placed on the designer's decisions.*

Interpretation of law: If the Law is *not* violated, it has no impact. If it *is* violated, it can be confidently predicted that the design Target (i.e., whatever description or product the individual or group seeks to achieve) will embody bad outcomes that are beyond the control of the designer, because the design process did not exhibit the Requisite Parsimony, but instead allowed the rate of flow of information to the designer to exceed processing capacity.

It may be questioned why designs have succeeded in the past without overt adherence to this requirement. Design Targets vary significantly in their scope. If the Law of Requisite Parsimony is being unknowingly violated, one would expect that the impact would be revealed in the failure of large system designs. This is precisely what is being observed all around the world.

Those who deny the validity of and those who doubt this Law must accept the burden of providing other explanations for failures. The often-rendered explanation 'operator error' may often, itself, reflect the same fundamental cause to which this Law responds in terms of the design process.

Brief 2: The Law of Structural Underconceptualization

Origin(s) of law: Empirical, Mathematical logic.

References: Warfield (1979, 1991a, 1994).

Statement of law: *No matter what the complex issue, and no matter what the group involved in its study, the outcomes of ordinary group process (i.e., process in which computer support for developing the formal logic structure of the issue is lacking) will be structurally underconceptualized (as evidenced, for example, by the lack of delineation of the cycles and of any structural connections among them).*

Interpretation of law: A proper interpretation of this Law requires an understanding of the fundamental nature of structure. The term 'structure' is widely used by economists in a very loose way, virtually as a semi-metaphor. This widely practiced usage simply serves to put a veneer on top of what can be very precisely defined. A proper interpretation of structure refers to how individual substantive components of information or knowledge are related.

To understand the foundations of relationships, one needs to know something about the history of the development of what is called 'the theory of relations' or 'the logic of relatives'. The most foundational work done in this area was carried out by a British professor, Augustus De Morgan, who published his treatise in the year 1847. Listen to how his work was described (sometime around the year 1867) by America's greatest philosopher, Charles Sanders Peirce:

> a brilliant and astonishing illumination of every corner and every vista of logic

But the direct connection of De Morgan's work to the structure of information or knowledge did not become crystal clear until the publication of a book by Professor Frank Harary and two junior colleagues at the University of Michigan in 1965 [Frank Harary, R.F. Norman, and D. Cartwright, *Structural Models: An Introduction to the Theory of Directed Graphs*, Wiley, New York].

In this book, Harary showed that any given relation corresponds directly to a particular graphical structure; and that every relation corresponds to some form of directed graph ('digraph') (although the utility of such a correspondence seems limited to the so-called 'transitive relations', a very large class).

Taking that information, Warfield showed in his 1976 book [*Societal Systems: Planning, Policy, and Complexity*, Wiley, New York] that the most general form of digraph representing a relation exhibited several attributes:

- A hybrid structure.
- Exactly two distinctive prototypical substructural types in a hybrid structure identifiable as either (a) hierarchy or (b) cycle.
- A numerical measure of the length of any hierarchical substructure.
- A numerical measure of the length of any cycle substructure.
- A numerical measure of the 'width' of a hierarchy, giving a numerical meaning to 'linear structure' as a hierarchy of width 1; and giving a numerical interpretation to the idea 'breadth of relationship'.
- A numerical measure of the structural complexity of a relationship based upon the structural features of the hybrid structure (and this measure of complexity has since been joined by several new ones discovered in recent years).

In that same work, Warfield presented a variety of algorithms for developing such structures with computer assistance, providing a methodology that allowed the structures of complex issues to be created by groups of knowledgeable people and, thereby, opening the way for the structure of knowledge to take its rightful place among the analytical and synthetic concepts available to people to analyze complex issues or systems, and to design such complex systems in a way that would make clear how the designs relate to the issues themselves, thereby eliminating the need for vagueness in the design of such systems as health care systems, systems for dealing with other public policy matters, as well as providing a similar benefit in the design of physical systems such as automobiles.

But in spite of these developments and the broad-ranging nature of the benefits that could

be attained by taking advantage of them, only a relatively small number of people have learned about this area and have begun to take advantage of what is known.

In the laboratory work done by Warfield and his colleagues, a considerable amount of data was taken based on work done by numerous groups with a variety of complex issues. These data showed typical attributes of the structures developed. It was found that over 97% of all structures were hybrid structures (i.e., they contained at least one cycle).

The most evident proof of structural underconceptualization in dealing with complex issues and complex systems is the failure even to identify the cycles that are present in the structures. A lesser evidential point is that frequently the hierarchical substructures are not identified. The set of hybrid structures required to show the underlying structure of information is virtually never constructed. If and when the set is constructed, it may be superficially rendered (as in Senge's 'archetypes') in non-operational form, leaving the actor to invent, without recommended processes, the more substantive and particular instances relevant to a given situation; which seemingly asks the actor to become a process inventor.

Hence the wide-ranging scope of the Law of Structural Underconceptualization. But it must be realized that structural underconceptualization always implies underconceptualization. The situation is as though a human body were presented without any skeleton. We would see a limp corpse with no definition of human shape. It is only the structural feature of the body that allows it to be erect or elongated, and provides the basis for its overall appearance.

How frightening can it be that in virtually every major public issue or virtually every large system design seen in our society, the structural descriptions are not even comprehended, and not made available for view and interpretation?

How disappointing and how demoralizing can it be that the latter is not being done, even though it is perfectly feasible to do it, to do it efficiently, and to do it in a responsible, high-quality way?

Brief 3A: The Law of Organizational Linguistics

Origin(s) of law: Empirical.

References: None.

Statement of law: *As an organization grows, linguistic separation grows both laterally and vertically in the organization. At the higher vertical levels, metaphors and categories become progressively disconnected from the relevant components at lower levels, leading to decisions based on perceived relations between categories that are not borne out by relations between the members of those categories.*

Interpretation of law: Imagine that a group of people is formed by selecting several individuals from the human race at random. Then suppose that exhaustive information is obtained which will reveal what language components are shared by every single member of that group. It may be that one of the members came from a remote tribe in Australia, and another came from a similarly remote tribe in the mountains of Peru. It may be that there is virtually no language component that is shared by the group.

The term 'linguistic domain' was applied by the Chilean scientist Maturana to describe the language commonality among a group of people.

It is easy to see that if a certain group effectively defines their linguistic domain, the extent of that domain will normally shrink as new members become attached to the group, unless some specific actions are taken to restore or enlarge the linguistic domain. Enlargement would require that every single member of the group take on the addition, whatever it might be, in order that an enlarged linguistic domain could be said to exist.

Now imagine a large organization which is hierarchically organized so that conversations mostly occur *within* rather than *across* organizational layers. Each one of these layers corresponds to a certain linguistic domain that holds within that layer. Yet as human turnover occurs in a layer the linguistic domain of that layer changes.

The maintenance of a linguistic domain relies on (a) usage of the existing domain to keep it at

the forefront of each individual's usable language, and (b) upgrading of the domain every time a new member enters, in order to prevent its deterioration.

Since big organizations do virtually nothing to maintain even a single linguistic domain, it is inevitable that over time people will only be able to talk to one another knowingly in a given layer and then, only in the fractional terms that remain after the natural progressive deterioration that goes on in these domains.

But deterioration of linguistic domains is often less affected by change in the human make-up of the relevant groups than it is by changing technology. In many industries, technological change causes significant demands to be made to incorporate new terminology in a linguistic domain, yet the technological terminology is often so poorly defined or so foreign that assimilation of it into a given domain can only be done if the organization pays the price. The price that has to be paid is that time of the affected individuals must be dedicated to human interaction aimed at renewing and strengthening the linguistic domain.

But even if linguistic domains are strengthened in a few layers of a large organization, still another phenomenon becomes critical. What is being talked about in the lower levels of the organization are often highly detailed subjects, these subjects never being discussed at that level of detail in the higher levels of the organization. If there is going to be linguistic connection between levels, one must recognize that the metaphors and categories (the high-level organizational language) have to have a strong correlation to the detailed information (the low-level organizational language), and that this correlation has to be sustained and renewed constantly in order to preserve meaningful communication across organizational boundaries.

Empirical observation of groups who work at different levels in organizations has shown that the relationships that high-level people construct and apply among metaphors and categories simply do not correlate with the lower-level ideas that high-level people assume are encompassed within those metaphors and categories. The result is that the decisions and actions taken at high levels in organizations often amaze the operating levels because they make so little sense and vice versa. The reason for the lack of sensibility is that both levels are operating in what might be called incongruous linguistic domains.

Until organizations understand the necessity for maintenance, renewal and cross-organizational development of linguistic domains, those ever-present trends that work against effective communication will continue to be responsible for what appears to the external observer as organizational incompetence.

Brief 3B: The Law of Vertical Incoherence in Organizations

Origin(s) of law: Empirical.

References: Alberts (1995), Cárdenas and Rivas (1995), Warfield (1995).

Statement of law: *For any large organization (that is unaware of this Law), there are invisible-but-potentially-discoverable patterns of vertical coherence awaiting discovery; which when discovered, will show how key features of that organization are (a) many in number, (b) can be structured into categories that are much fewer in number, and (c) whose categories can be structured into areas that are again much fewer in number. The features include problems, available small-scale options for resolving the problems, and other element types yet to be discovered. This structure will be an 'inclusion structure' from the class of Application Structural Types described in* A Science of Generic Design.

Interpretation of law: This Law relates to what I have called the 'Alberts Pattern', based on work done first by Henry Alberts and later by Roxana Cárdenas and Jose Rivas.

Further elaboration of this Law indicates that the three levels in the Pattern can typically be correlated strongly with what have historically been called the Operational Level, the Tactical Level, and the Strategic Level; and those in turn can typically be correlated with Front-Line Management/Labor, Middle Management, and Top Management.

Still further elaboration comes from evidence that these three stratified levels are not

adequately understood in organizations, and that many bad organizational decisions at each level come about because of this lack of understanding.

Brief 4: The Law of Validation

Origin(s) of law: Philosophy of science, as originated by Charles Sanders Peirce.

References: Churchland (1986), Deely (1991), Goudge (1969), Warfield (1994).

Statement of law: *The validity of a science depends upon substantial agreement within the scientific community of meaning at its highest grade, i.e., meaning attained through Definition by Relationship.*

Interpretation of law: Many philosophers believe that they understand the concept of valid knowledge. The people that they like to refer to include Auguste Comte, Thomas Kuhn and Karl Popper. Others, who hear these people being named as the origins of the appropriate views about what constitutes valid knowledge, are likely to accept their views without question, based on the assumption that the philosophers have adequately explored the presuppositions underlying the views of people such as Comte, Kuhn, and Popper.

In contrast, the mature philosophy of Charles Sanders Peirce presents a philosophy of science that is not consistent with any of the foregoing. Moreover, John Deely has clarified what is wrong with the popular view of scientific validity, and has made clear why the popular view that there exists observer-independent 'objective knowledge', which has a higher quality than ordinary knowledge, is misbegotten.

To get a hearing, one must proceed as follows:

- Explain why the prevailing views are wrong (that takes quite a bit of time and argument).
- Explain what the appropriate views are (that requires quite a bit of background from the listener, which most of them who are 'college-educated' lack).
- Explain why the latter views are appropriate.

Since that can't be done in a short space, we have to appeal to the reader and make a promise to the reader. The appeal is to suspend belief in the commonly accepted ideas and take an interest in exploring another point of view. The promise is that the reader who will spend enough time studying the matter can get virtually all of the important ideas from the references given here.

Brief 5: The Law of Diverse Beliefs

Origin(s) of law: Empirical.

References: Warfield (1991b, 1993, 1994, 1995).

Statement of law: *Whatever the group, whatever the complex issue being considered by the group, at the outset of group consideration of the issue, the individual members of the group will have quite diverse beliefs about the issue; and the probability is high that this situation will remain undiscovered and uncorrected, in the absence of a group learning experience using a methodology whose power to produce the necessary learning has been scientifically validated.*

Interpretation of law: In order for people to share a common point of view about a complex issue, several conditions must be met. The age-old philosophical Doctrine of Necessity underpins this idea:

- People must all share the same linguistic domain, in order that they can even conceive and express jointly and sincerely the same point of view.

But in complex areas, empirical evidence shows that people do not share an adequate linguistic domain, and frequently cannot even understand the initially expressed points of view of others because they lack the substantive background knowledge or experience to do so. If they do not even share a common meaning of a critical word or phrase, they will not be able to express any shared point of view that they might hold, or even test whether they hold a shared point of view.

Even in the instances where they do share the same linguistic domain (which our research shows to be a rare situation, much rarer than almost anyone would likely believe until an opportunity is made available to observe appropriate human interactions), some believe that

dramatic differences of opinion are a consequence of very different value orientations of individual people. But consider this. If people do not share a linguistic domain that is broad enough to enable them to express and share a common point of view, it will never be possible even to determine the existence or relevance of the influence of presupposed different value orientations. Therefore, even if the proponents of the differing values theory are correct, there is no way for them to establish their correctness in the absence of prior conditions.

Since the evidence of lack of sharing an adequate linguistic domain is compelling, one must give credence to the former. But even if this lack is discounted, the empirical evidence shows very clearly the absence of shared belief among groups of people who are supposedly knowledgeable in areas. So whatever the reason for this absence, the Law stands as an empirical fact.

This Law should compel a certain kind of behavior on the part of leaders who see value in developing a shared point of view. The kind of behavior that is required is to create conditions whereby the linguistic domain of that group of individuals whose diversity of views creates unmanageable or ineffective organizational conditions is enlarged to the point where it becomes feasible to enunciate and share a point of view.

If the leadership is unable or unwilling to do this, at least the leadership should recognize the value in knowing that virtually all individuals in the pertinent group have quite diverse beliefs about any complex issue. The potential benefit that may be seen by a leader is to enter the policy or action vacuum and promote one's own point of view based on the held authority. The potential dysbenefit that might be seen by a leader is that the leader is usually no different from any other of the relevant individuals. The leader's views are just as likely to be unsatisfactory as those of any of the others.

Brief 6: The Law of Gradation

Origin(s) of law: Theory of Relations: Inclusion Relation.

References: None.

Statement of law: *Any conceptual body of knowledge can be graded in stages, such that there is one simplest stage, one most comprehensive stage (reflecting the total state of relevant knowledge), and intermediate stages whose content lies between the two extremes.*

- *The Corollary of Congruence. The* first Corollary *to this Law asserts that the class of situations to which a conceptual body of knowledge may apply, in whole or in part, likewise may be graded according to the demands that individual situations can reasonably make upon the body of knowledge. This is called the* Corollary of Congruence, *because it relates to the congruence between the Design Situation and Target with a restricted grade of the Generic Design Science that is called into play in the specific case. Clearly the designer is not required to uncover every detail of relevance, no matter what the cost. When in doubt, a conservative posture will call for erring on the side of the higher grade.*
- *The Corollary of Diminishing Returns. The* second Corollary *to this Law is the existing economic* Law of Diminishing Returns, *which states that the application of a body of knowledge to a Design Situation should be made through that stage at which the point of diminishing returns to the Situation (as opposed to only the user) is reached. This is called the* Corollary of Diminishing Returns, *and it highlights a major responsibility of the designer to make judgments about when this point is reached. Once again, a conservative posture will call for erring on the side of the higher grade.*
- *The Corollary of Restricted Virtual Worlds. The* third Corollary *to this Law states that the identification of the stage at which diminishing returns to the situation is reached normally requires the integration of the Virtual Worlds of the affected parties in the situation in relation to the dimensions of the situation. This is called the* Corollary of Restricted Virtual Worlds, *and it reflects the need for a global point of view in making the kinds of judgments that are required to achieve the appropriate congruence of gradation.*

Interpretation of law: The importance of this Law to the Science of Generic Design lies in the guidance that it provides to the designer concerning how to perceive any particular

Design Situation with respect to the Science. In this respect, one notes that design Targets may range from very small, limited-scope Targets to very large, broad-scope Targets.

It is *not* reasonable to take as a criterion for Generic Design Science that all of its Theory and all of its Methodology should be demonstrably required for all design activity. On the contrary, such a Science would be too brittle for use. The Law of Gradation overtly recognizes that Design Situations and Design Targets are themselves graded according to a variety of descriptions, not all of which can be foreseen. Accordingly, the Science of Generic Design should be applied judiciously, extracting from it one of its stages that is most appropriate for the particular Design Situations and Design Target.

The word 'generic' does *not* mean 'always required'. What it *does* mean is 'covering the set of gradations of Design Situations and Targets as a whole, without overlapping the applicable Specific Design Science; but subject to judicious restriction commensurate with the grade of the Design Situation or Design Target in any partcular instance'.

It is *not* the function of a Science of Generic Design to provide a recipe appropriate to every Design Situation. It *is* the function of such a Science to actuate the designer's professional responsibility to assess and correlate the gradation in the Situation and Target against the total sweep of the Generic Design Science, and to choose that restricted version of the Science which will be used openly, rather than to accept subliminally a restricted version that leads to underconceptualization of the Design Situation and the Design Target. It is the further function of the Generic Design Science to provide the means of documentation consistent with what the Design Situation requires.

Brief 7: The Law of Universal Priors

Origin(s) of law: Empirical.

References: Warfield (1994).

Statement of law: *The human being, language, reasoning through relationships, and archival representations are universal priors to science (i.e., there can be* no *science without each of them).*

Interpretation of law: *The Doctrine of Necessity.* The validity of this Law can be established using what is called the Doctrine of Necessity. This Doctrine holds that, independent of the particular attributes of B, if A is necessary in order for B to exist, then A is a prior of B. (The word 'prior', used as a noun, fills a need that no other word quite satisfies.) The test of the necessity of each of the four factors mentioned is to imagine that they are withdrawn, and then inquire as to whether in their absence a science is possible.

- *The Human Being*. Imagine first that there were no human beings. Accepting the common evidence that human beings are the producers and the only producers of science, then it must be that the human being is a Universal Prior to Science.
- *Language*. Imagine next that no language were available. Since all of science consists of language, and nothing other than language, there can be no science without language.
- *Reasoning Through Relationships*. Suppose now that there is no reasoning through relationships. Since all organization of information is through relationships arrived at by reasoning, there can be no organization of knowledge without it. But science *is* organized knowledge, hence both language and reasoning through relationships are Universal Priors to Science.
- *Archival Representation*. The human being, language, and reasoning through relationships all can exist and persist without any archival representation, the organization being in the mind. It might, therefore, be argued that these three are sufficient, and that archival representation is not required in order for organized knowledge and, therefore, science to exist. But science depends upon widespread consensus, and library after library attests to the critical importance of archival representation in gaining the necessary widespread understanding and consensus upon which acceptance as science depends.
- *Absence of Foundations*. Overt recognition of the status of the Universal Priors to Science should

bury the modest movement to assert that there are *no* foundations to (at least some) sciences. On the contrary, what is seen here not only states that there *are* some, but there are some that are foundations to *all* science. If one is to distinguish one science from another, it may be through finding unique foundations for a *particular* science that can and must be integrated with the Universal Priors to establish the decision-making basis for the particular science.

- *Diminution of Universal Priors*. One obvious, but misguided, way to try to provide distinctiveness to the foundations of a science is to lay the Universal Priors on the operating table, and to diminish them to shadows of their identity, while retaining slices of them. Thus the human being may be fractionated into an economic entity, a social entity, or other one-dimensional entity such as political, athletic, biological, etc., or through a role such as observer of nature. Language may be diluted by failure to establish and enforce the definitions of its components, and reasoning through relationships may be diluted both by blurring the definitions of the relationship terms and by disguising patterns of relationship. The latter can occur naturally because of the linear sequential nature of prose, which does not lend itself to portraying patterns. Archival representations may themselves be so diluted by the emaciation of the other three Universal Priors as to be helpless to offer any assistance in searching for Referential Transparency.

Brief 8A: The Law of Inherent Conflict

Origin(s) of law: Empirical.

References: Warfield (1991b, 1993, 1994, 1995).

Statement of law: *No matter what the complex issue, and no matter what the group involved in its study, there will be significant inherent conflict within the group stemming from different perceptions of the relative significance of the factors involved in the complex issue.*

Interpretation of law: The interpretation of this Law is essentially the same as that for the Law of Diverse Beliefs. The latter offers an explanation for the Law of Inherent Conflict. Because the beliefs are diverse, there is inherent conflict within the group. The two Laws mentioned here are complementary and can often be seen as a composite that could be called the Law of Diverse Beliefs and Inherent Conflict. Nevertheless it is believed that the modest redundancy involved is not adequate justification to repeal the decision to present the two Laws separately. Each Law offers its own unique point of view.

In order for people to share a common point of view about a complex issue, and thereby avoid conflict on that issue, several conditions must be met. The Doctrine of Necessity underpins the idea that one condition is:

- *People must all share the same linguistic domain, in order that they can even conceive and express the same point of view.*

But in complex areas, empirical evidence shows that people do not share an adequate linguistic domain, and frequently cannot even understand the initially expressed points of view of others because they lack the substantive background knowledge or experience to do so. If they do not even share a common meaning of a critical word or phrase, they will not be able to express any shared point of view that they might hold, or even test whether they hold a shared point of view.

Even in the instances where they do share the same linguistic domain (which our research shows to be a rare situation, much rarer than almost anyone would likely believe until an opportunity is made available to observe appropriate human interactions), some believe that dramatic differences of opinion are a consequence of very different value orientations of individual people. But consider this. If people do not share a linguistic domain that is broad enough to enable them to express and share a common point of view, it will never be possible even to determine the existence or relevance of the influence of presupposed different value orientations. Therefore, even if the proponents of the differing values theory are correct, there is

no way for them to establish their correctness in the absence of prior conditions.

Since the evidence of lack of sharing an adequate linguistic domain is compelling, one must give credence to the former. But even if this lack is discounted, the empirical evidence shows very clearly the absence of shared belief among groups of people who are supposedly knowledgeable in areas. So whatever the reason for this absence, the Law stands as an empirical fact.

This Law should compel a certain kind of behavior on the part of leaders who see value in developing a shared point of view. The kind of behavior that is required is to create conditions whereby the linguistic domain of that group of individuals whose diversity of views creates unmanageable or ineffective organizational conditions is enlarged to the point where it becomes feasible to enunciate and share a point of view.

If the leadership is unable or unwilling to do this, at least the leadership should recognize the value in knowing that virtually all individuals in the pertinent group have quite diverse beliefs about any complex issue. The potential benefit that may be seen by a leader is the opportunity to enter the policy or action vacuum and promote one's own point of view based on the held authority. The potential dysbenefit that might be seen by a leader is that the leader is usually no different from any other of the relevant individuals. The leader's views are just as likely to be unsatisfactory as those of any of the others.

Brief 8B: The Law of Limits

Origin(s) of law: Empirical.

References: None.

Statement of law: *To any activity in the universe there exists a corresponding set of Limits upon that activity, which determines the feasible extent of the activity.*

- *The Corollary of Active Limits. The* first Corollary *to this Law asserts that for any particular situation, the set of Limits can be partitioned into two blocks: an* active *block and an* inactive *block. This Corollary is called the Corollary of Active Limits. The active block is the subset of the set of Limits that is determining at a given time, while the inactive block is not determining at that time. The active block may often consist of a single, dominating member of the set of Limits. Such a member may be so strong in its power to limit that, in effect, all other Limits are forced into hiding by the dominant one. When this occurs, it has both advantages and disadvantages. An advantage is that the designer who recognizes this situation can focus attention upon the dominant Limit and look for ways to modify its impact. A disadvantage is that the non-active Limits may go unrecognized, only to make their impact felt later upon the design activity that has focused overly on overcoming the dominant Limit.*
- *The Corollary of Movable Limits. The* second Corollary *to this Law asserts that the set of Limits also can be partitioned into these two blocks:* movable *and* fixed. *A movable limit is one that can be altered, while a fixed limit is one that is unchanging. Clearly if there is a dominant Limit and it is fixed, the potential exists for wasting substantial amounts of time, effort, and resources if one does not understand that it is fixed. On the other hand, if one mistakenly assumes that a Limit is fixed, when it really is movable, the potential exists for missing opportunities for major improvements. This Corollary is called the* Corollary of Movable Limits.
- *The Corollary of Discretionary Action. The* third Corollary *to this Law asserts that the movable subset of Limits can be partitioned into these two blocks: movable through* discretionary action *by people, and* autonomously *movable. Limits that are autonomously movable change on their own, and thereby drive the system. Clearly the strategic posture for dealing with such Limits is to maintain cognizance of their status and to have some predetermined alternatives in mind for coping with them when they move into prominence. This Corollary is called the* Corollary of Discretionary Action. *Limits that are movable through discretionary action by people are, of course, those that should be clearly recognized by designers, and to which attention should be given in the event that they are not overshadowed by more prominent Limits that effectively nullify the latent impact of those lying in the background.*

- *The Corollary of Shifting Limits. The* fourth Corollary *to this Law asserts that the membership of the active blocks and of the inactive blocks of the partitions changes with time. If, for example, discretionary action brings about a change in some movable Limit that previously was dominant, one or more new Limits will take the place of the previously dominant Limit. This is the* Corollary of Shifting Limits.

Interpretation of law: The significance of this Law to the Science of Generic Design is that it conveys the importance of discovering (a) what the Limits may be upon design in general and how these Limits may relate to any particular Design Situation and (b) those additional Limits that are at work in a particular Design Situation. This Law and its Corollaries impose upon Theory the requirement that it contain explicit identification of generic Limits and explicit provision for the incorporation of special Limits.

The Law of Limits itself provides no means of identifying the Limits or of partitioning them after they have been identified. This capability must arise from other sources.

Brief 8C: The Law of Requisite Saliency

Origin(s) of law: Empirical.

References: Boulding (1966), Warfield (1994).

Statement of law: *The situational factors that require consideration in developing a design Target and introducing it in a Design Situation are seldom of equal saliency. Instead there is an underlying logic awaiting discovery in each Design Situation that will reveal the relative saliency of these factors.*

Interpretation of law: Kenneth Boulding identified three major reasons for poor intellectual productivity. These are: *spurious saliency* (emphasizing the wrong things, out of proportion to what they deserve); *unproductive emulation* (behaving like those who help create rather than resolve problems); and *cultural lag* (not using established knowledge with dispatch). Characteristically individuals who become involved in the design process *exhibit great diversity in their assessment of relative saliency* (as indicated in the data in Appendix 5 of *A Science of Generic Design*). This diversity, if uninfluenced by thorough exploration of the Design Situation, will support unfocused dialog, unjustified decisions, and arbitrary design outcomes not likely to be understood or even actionable.

The design process must incorporate specific provision for uncovering the relative saliency of the factors in the Design Situation and the factors that characterize the Target, in order to achieve the kind of understanding that is needed to put the design factors in proper perspective.

Brief 8D: The Law of Success and Failure

Origin(s) of law: Mathematics of discrete probability.

References: Warfield (1958, 1965, 1968).

Statement of law: *There are seven critical factors in the SUCCESS BUNDLE for the Design Process. Inadequacy in any one of these factors may cause failure. The seven factors are: leadership, financial support, component availability, design environment, designer participation, documentation support, and design processes that converge to informed agreement.*

Interpretation of law: This Law indicates that a Science of Generic Design must define the critical factors in sufficient depth to enable (a) the assessment of their adequacy and (b) their application in the Design Situation. Success and failure must also be elaborated and, in this context, success in all stages of work, including the implementation and operation, is required in order to proclaim that the design is successful; while failure in any stage is sufficient to constitute failure of the design.

This Law furnishes the impetus for what is called the Sigma-N Concept, discussed in detail in Sec. 6.9 of *A Science of Generic Design*.

Brief 8E: The Law of Uncorrelated Extremes

Origin(s) of law: Empirical, Statistical Analysis.

References: Kapelouzos (1989), Warfield (1994), Warfield (1995).

Statement of law: *No matter what the complex issue, and no matter what the group involved in its study, the* initial *aggregate group opinion concerning the logical pattern of the factors involved in the issue and the* final *aggregate group opinion concerning the logical pattern of the factors involved in the issue (i.e., the views at the two extremes of the application of the Generic Design Science, before and after), will be uncorrelated; showing that significant learning takes place through the application of the generic design processes.*

Interpretation of law: Once it was discovered that there was very great diversity in the views of individual members of groups about the relative importance of elements that were generated and clarified using the Nominal Group Technique (NGT), a research question arose about the persistence of such views after additional work was done. Since such elements were typically the subject of structuring work using Interpretive Structural Modeling (ISM), a natural way to approach this question involved a comparison of the results obtained using ISM with the products of the voting done as part of the use of NGT.

While NGT is not regarded as a structuring tool, nevertheless a structure can be produced from the results of NGT voting. Here is how such a structure can be produced. For each problem element that gets at least one vote from a participant in group work using NGT, make numerical assignments to those votes as follows:

> The highest rated element coming from some individual's voting gets a score of 5; the second highest rated element from that same individual's voting gets a score of 4; and so on, until the fifth-rated (lowest-rated) element gets a score of 1. Assigning such scores for every individual's votes, one can then compute a cumulative score for each element that received a vote. A structure can then be created using the relationship 'has a higher score than', and this relationship can be regarded as equivalent to 'is perceived by the group as a more important problem than'.

Conducting the ISM session with the same elements, typically a problematique structure is produced using the relationship 'aggravates'. A method of scoring was developed whereby each problem element in the problematique receives a certain net score. This net score reflects the position of the problem element in the problematique, and takes into account the number of other problems that are aggravated by a given problem, as well as the number of problems that aggravate a given problem. Typically problems lying at the left will get larger scores than those lying at the right of the structure.

It then becomes possible to correlate the scores coming from the NGT-derived structure with the scores coming from the ISM-derived structure. While the two structures do not share precisely the same relation, one is justified in presuming that those problems that aggravate many other problems are more important than the ones they aggravate because of their power to sustain those other problems; while those that are, in effect, continued with increased power to do harm by others are regarded as less important. Importance thereby takes on a priority status, and reflects the potential strategy of attack, working first on those that have the greatest power to aggravate other problems. Some data exist to show that this strategy has been very successful.

Judge I.B. Kapelouzos, who was on sabbatical leave from his position on the Council of State of Greece, decided that he would study 31 cases for which data were available to examine the before-and-after correlation for such structures. The 'before' structure was the one produced from the NGT work, and reflects composite group results just before the ISM work begins. The 'after' structure is the one that is available after the ISM work is finished.

People familiar with these concepts assumed that the work would show some variation from perfect correlation. Everyone was surprised to see the results. The results showed no correlation between the before-and-after structures. The startling nature of this result could only be explained in one way: the individuals in the group, after having gone through a rigorous examination of the relationships among the problems, learned a great deal about how those problems interact (something which they could not readily do otherwise, as indicated by the Law of Triadic Compatibility); and as a result the type

of strategy indicated by their product changed dramatically as a result of this learning.

These research results imply, among other things, that all those methodologies currently in vogue for group work, which do not incorporate in their tool kit the ISM process whereby detailed examination of interactions among elements is carried out by the group, are sorely deficient and are likely to produce very misleading and dysfunctional conclusions.

Much more is learned from the process of detailed study of interactions among elements than intuition had suggested. Even though ISM was specifically designed to be a learning process, it was not envisaged that it would have the power which the Law of Uncorrelated Extremes attaches to it. Further research along these lines should be very valuable in adding to our limited knowledge concerning such matters.

Additional evidence to support the conclusions embodied in this Law are reflected in the Law of Structural Underconceptualization, where the data show unequivocally that individuals and groups do not even produce structures without the help of the ISM process, as discussed in the Interpretation of that Law!

Brief 8F: The Law of Induced Groupthink

Origin(s) of law: Empirical.

References: Allison (1971), Janis (1982), Warfield and Tiegen (1993), Warfield (1994).

Statement of law: *The pathological behavior described as 'Groupthink' (e.g., in the work of Irving Janis, and in Graham Allison's study of The Bay of Pigs incident), can be predictably induced in groups by the behavior of individuals who put pressure on groups to produce results under a time limit; where complexity is paramount.*

Interpretation of law: This Law, related to Groups, has its parallel in the Law of Forced Substitution, intended to explain certain behavior of a top-level executive.

The case study work done by Graham Allison, and the more elaborate and detailed case studies reported by Warfield and Tiegen in the 1993 document titled 'Groupthink, Clanthink, Spreadthink, and Linkthink', illustrates what this Law says.

Brief 9: The Law of Requisite Variety

Origin(s) of law: Mathematics, Systems Theory.

References: Ashby (1958), Warfield (1986), Warfield and Christakis (1987), Warfield (1994).

Statement of law: *A Design Situation embodies a requirement for Requisite Variety in the design specifications. Every Design Situation S implicitly represents an (initially unknown) integer dimensionality K_s such that if the designer defines an integer K_m number of distinct specifications (whether qualitative or quantitative or a mix of these), then:*

(i) *If $K_m < K_s$, the Target is* underspecified *and the behavior of the Target is outside the control of the designer.*

(ii) *If $K_m > K_s$, the Target is* overspecified, *and the behavior of the Target cannot be compatible with the designer's wishes.*

(iii) *If $K_m = K_s$, the design specification exhibits Requisite Variety, provided the designer has correctly identified and specified the dimensions; and the behavior of the design should be that which the Situation can absorb and which the designer can control, subject to the requirement that the dimensionality of the Situation is not modified by the introduction of the Target into the Situation.*

If the dimensionality is changed thereby, the design process can apply the Law of Requisite Variety iteratively, taking into account the dynamics of the Situation.

Interpretation of law: The Theory of Dimensionality has been introduced, in part, to make possible this formulation of the Law of Requisite Variety, especially to enhance applicability of it to those situations where some dimensions are naturally quantitative and some are naturally qualitative, requiring that both kinds of dimensions be in a common space and subject to comprehensive interpretation in order to achieve a sound design result.

The question might be raised as to how designers have succeeded in the past in the

absence of overt response to this Law. Many, if not most, Targets of design are redesigns that benefit from decades of experience which have permitted the development of intuitive knowledge that substitutes for overt application of this Law. Regrettably, it is this same cumulative experience that mistakenly leads designers and their managers to believe that somehow they can intuitively design systems much larger in scale that have never been designed before.

Brief 10A: The Law of Forced Substitution

Origin(s) of law: Empirical.

References: None.

Statement of law: *Structural underconceptualization and inherent conflict lead to policy vacuums in an organization into which authority injects forced substitution for absent and inadequate conceptualization, in order to avoid institutional paralysis and for self-protection.*

Interpretation of law: This Law reflects the empirical knowledge that executives in charge of large organizations are essentially forced to take action in regard to problems of the organization. The very large pressures on such executives will be relieved in the short run by taking action. A question of much importance has to do with how effective such action will be.

It has been pointed out by Peter Senge that while executives often have significant amounts of experience on short-term issues of relatively little complexity, such executives often have no reliable experience regarding longer-term issues which are complex. A simple explanation is that by the time the consequences of the decisions they make are felt, those executives have changed positions, and are not even around to experience directly those consequences. Another explanation has to do with the fact that complex issues are quite small in number compared to the many normal issues facing organizational leadership, so even the statistics work against gaining relevant experience. It is unreasonable to expect that the executive who is making decisions about complex issues is any better equipped to make such decisions than anyone else inside or outside the organization.

The combination of being required to make a decision about a complex issue and the lack of high-quality analysis and experience related to that issue is perfectly calculated to produce action that will not be effective and may make matters worse.

Because it is possible to apply methodology that is compatible with and recognizes the importance of the Laws of Complexity, it is reasonable to postulate that such an analysis or design could have been produced if the leadership were both aware of and willing to sponsor such activity. The choice of the term 'Forced Substitution' recognizes that the decision-maker is substituting a 'hip-pocket' or 'wet-thumb' decision for what could have been a highly informed decision, informed, among other things, by the structure of the issue; and that the decision-maker is forced by circumstances to make such a decision because to do otherwise would convey an image of ignorance and indecision which (even though it might well be warranted) is not what boards of directors are willing to tolerate.

They will accept bad decisions (unwittingly or otherwise), unsupported by the kind of analysis and design that is now possible to attain taking into account knowledge of the Laws of Complexity, but they will not support inaction.

Brief 10B: The Law of Precluded Resolution

Origin(s) of law: Empirical.

References: None.

Statement of law: *Forced substitution in organizations is dominated by the combination of:*

- *structural underconceptualization;*
- *inherent conflict and diversity of belief;*
- *dysfunctional organizational linguistics;*

which combine to preclude resolution of complex issues.

Interpretation of law: This Law is intended to explain the reasons why complex issues are seldom resolved in organizations. The

explanation is given in terms of what several other Laws of Complexity have to say.

Recognizing that there is much diversity of belief, and much inherent conflict in the views of individuals concerning the relative importance of various elements germane to a complex situation, at the beginning the organization is in intellectual disarray about the complex issue.

If the organization does not have any effective methodology for learning about the issue, and if it does not use the process of Interpretive Modeling to develop the structural patterns that explain the issue (and very few organizations presently do this), whatever individual's particular uninformed perceptions become the basis for action will necessarily exhibit structural underconceptualization, and will then promulgate an uninformed approach to an implementation scheme already lacking support in the organization.

In the absence of any well-designed means for developing the necessary organizational linguistic domains, people will not even be able to share a mutual understanding of what was wanted and therefore cannot be effective or even mutually reinforcing in implementing bad decisions emanating from a perceived requirement to take some action.

In other words, there is an overwhelming set of institutional conditions that virtually guarantee that complex issues will not be resolved, and the analysis that explains the reason for the persistence cannot help but be supported by the anecdotal evidence being seen in everyday life as to the ineffectiveness and dysfunctionality of systems put in place with improper designs that are unresponsive to the situations they were purported to remedy.

Brief 11: The Law of Triadic Necessity and Sufficiency

Origin(s) of law: Mathematical Logic.

References: Brent (1993), Burch (1991).

Statement of law: *Relations are characterized by the number of distinct relational components, but no matter how many such components a relation may have, the (complex) relation can always be expressed by component relations having no more than three relational components; but triadic relations exist that cannot be expressed in terms solely of dyadic and monadic relations.*

Interpretation of law: Charles Sanders Peirce studied the logic of relations extensively. In the recent (1993) biography of Peirce by Joseph Brent, the following passage appears:

> Abstract forms of relation are objects of a mathematical inquiry called the logic of relations (or relatives), which Peirce began to examine in 1870 with his 'Description of a Notation for the Logic of Relatives'. By 1885 he had proposed in what Hans Herzberger [Professor of Philosophy, University of Toronto] has called 'Peirce's remarkable theorem,' that there are only three fundamental kinds of relations: monadic, dyadic, and triadic; that by combining triads, all relations of a greater number than three can be generated; and that all those of a greater number than three can be reduced to triads. Since, in addition, triads cannot be reduced to dyads, nor dyads to monads; monads, dyads, and triads constitute the fundamental categories of relations. At the same time, triads are made up of dyads and monads, and dyads of monads.

According to Robert W. Burch [Professor of Philosophy at Texas A & M University], others who have examined related issues include Quine, Löwenheim, Schröder, Herzberger, and Ketner. The following passage appears in Burch's 1991 book referenced above:

> By extending both the algebraic ideas of Herzberger and the graph-theoretical ideas of Ketner, this work proposes to develop an algebraic formalism in which a reduction thesis similar to and perhaps identical to the reduction thesis Peirce had in mind can be proved for the general case. This work also proposes to show that the reduction thesis it proves is consistent with the work of Löwenheim and the result of Quine, despite the fact that these results may appear to conflict with it.

The proof developed by Burch is long and thorny, but it has been examined by other mathematicians who have not detected any flaw.

If we accept the proof at face value, then we are impelled to note the interesting comparison of this Law with the Law of Triadic Compatibility. Putting the two together we arrive at the result that the number 3 not only is the maximum number of elements whose interactions can reasonably be dealt with in short-term memory because of the limits of recall, but also it coincides with the maximum number of elements that must be dealt with modularly in order to be able to deal with complex relationships of any magnitude.

The full significance of the foregoing is unclear at the present time, because of the limited amount of investigation into the consequences of accepting all of the foregoing as established scientific fact. But the potential significance is so great, and the absence of any evinced alternative other than to continue the present disjointed incrementalism ('muddling through') advocated by Braybrooke and Lindblom and so commonly practiced in organizations; provide strong motivation to those who are severely concerned with the defects in present organizational practice to move ahead; on the basis of the hypothesis that what is said in the foregoing paragraph is both true and the appropriate guidance for changing organizational practice and culture.

Brief 12: The Law of Small Displays

Origin(s) of law: Empirical.

References: Martin and McClure (1985), or almost any user guide to computer graphics software.

Statement of law: *Individuals, faced with a responsibility to help illuminate complexity, will typically fail to distinguish complexity from normality in their choice of media for displaying their work, and will continue to accommodate their behavior to the constraints imposed by small display media (e.g., $8\frac{1}{2} \times 11$ inch or A4 paper size, and/or small computer screens and standard-sized transparencies), instead of insisting on matching the size of display space to the complexity of the subject matter.*

Interpretation of law: If one imagines a scale related to complexity of issues, ranging from the very simplest imaginable to the most difficult imaginable, one can then consider how the scale of representation enlarges as the scale of the issue enlarges. Notably a point is reached where, as the complexity grows, the scale of representation stops changing at the point where conventional media have established benchmark dimensions.

Even the university has established a standard size of chalk board, as though no matter what is being taught can be represented within that scale. This assumption goes hand in hand with another; which is that linear, sequential presentations are the only kind that will ever be used in representing subject matter. The fact that the latter belief is readily contradictable seems irrelevant to university administrations. Why choose the university as a focal organization? Because it is this institution that blesses the practice by carrying it out repeatedly, day after day, to all of its clientele; thereby setting a standard for society to follow. It is, therefore, the same institution that could change the practice, simply by acknowledging it and creating an infrastructure to deny its universality.

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