Creating an interactive systems science program in higher education[1]

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An interactive systems science program should be initiated in higher education, rigorously based in the traditional concept of science set forth long ago by Aristotle and summarized in modern times by Charles Sanders Peirce. The program should be housed in its own facility but organically connected to a university through an interaction budget, with strong administrative contractual support, based on a new-resource strategy. A model program is described which can serve as a basis for a contractual arrangement. The program is identifiable as The Horizons College, focusing upon system design. The College provides services to respondents who bring "nitrogen situations" to the College, where these situations become the object of actions using The Work Program of Complexity, which is the action face of a well-defined version of systems science. A twelve-point framework outlines the program, which is sufficient to lay a sound basis for initiation and continuation of a systems science program in higher education, in spite of the numerous challenges that are faced by this proposal.

Keywords: Systems science; Complexity; Horizons College; Program design; Higher education; Nominal Group Technique (NGT); Interpretive Structural Modeling (ISM)

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1 Introduction

Obstacles to initiating and sustaining systems science programs in higher education have been identified (Warfield 2007a). That overview described twenty obstacles emphasizing the vulnerability of systems science programs in terms of the inherent nature of science itself and of systems science in particular. Also mentioned was a virtual conspiracy, in which numerous forces act against the initiation and continuation of such programs (though without formal agreement or even, necessarily, intent, but with equivalent intensity as though there were formal agreement or intent) with unfortunate consequences.

This paper offers a program design for a well-defined, interactive systems science program in higher education based upon several decades of experience in working with complexity (Warfield 2006). It is described in outline by a twelve-point design whose features have been tested to the extent possible without a prolonged institutional home, and found to be effective. Prior to a more detailed discussIon, the twelve points, summarized in "key phrases" are presented in Table 1, where the principal portion(s) of the paper that discusses the point is identified in parentheses:

Table 1. Twelve-Point Framework for Interactive Systems Science Program	
• Adapted scientific tradition (3)	• Linguistic integrity with colloquial referents (2)
• Complexity metrics (5.3)	• New resource strategy (6.1)
• Diverse respondents (2.4, 4.2)	• Project followup and reporting (6.3)
• Flexible observatorium arrangements (4.4)	• Strong spatial scanning facilities (3.3.7)
• Interaction budgeting (6.2)	• Structural hypothesis (3.1, 3.2)
• Laboratory component (3.3)	• Triadic scientific foundation (5)

2 Linguistic integrity with colloquial referents

One of the most astute observers and wise practitioners of the systems field, the late Sir Geoffrey Vickers, commented on the debasement of language and the difficulties this posed for authors (Vickers 1980). It is strange that recognition and application of his insight in practice seems to be limited to just a few of the most notable authors.

It is a daunting task to discuss the design of a systems science program when the word "systems" and the word "science" have both been diminished in scope or scale by indiscriminate usage. The task is made more difficult when, as in applications of systems science, the information that is required to resolve difficult situations is so often in the hands of people who are not accustomed to rigorous scientific language, whether debased or not; and may not even be aware of this fact **(Warfield 2004)**.

To make inroads on this difficulty, a twofold approach is required. On the one hand, it is necessary to adopt a language that is scientifically sound with respect to the kinds of situations one expects to find in systems science. On the other hand, it is necessary to match such a language with colloquial referents that can be made meaningful rapidly to local interests without having to spend long periods of educational time that overburden those interests.

2.1 Oxygen and Nitrogen Situations

The *scientific* basis for necessary linguistic adjustments has been discussed in detail (Warfield 2004). Some aspects of the *colloquial* basis have also been discussed (Warfield, 2007b), but not to the extent necessary for present purposes. The most important aspects of the colloquial basis involve the distinction between what I have elected, **in the interests of brevity,** to describe as "oxygen" situations and "nitrogen" situations. These distinctions take descriptive advantage of the commonly-understood mutual presence of oxygen and nitrogen in air; comparable to the much-less understood, but very analogous, mutual presence of ordinary situations and situations involving complexity in the world around us. **It is necessary to make strong linguistic distinctions to counteract the prevalent assumption that essentially all "problems" fall into one massive cognitive category; rather than lying in two very distinctive categories. Once sensitized to this necessity, the reader may find it amusing to go back through existing literature and note the lacunae in even mentioning the possible importance of a partition in the cognitive domain with respect to the manner in which issues are approached and embraced. A much more comprehensive discussion of the necessity for such a partition and the consequences thereof is available in the literature (Warfield 2002).**

Scientific study revealed ways to separate oxygen and nitrogen from air, enabling the vast differences between these two gases to be understood, even though they occupy the same space around us. A similar revelation must be recognized between the ordinary situations that take advantage of the scientific legacy (described as "oxygen situations") and those problematic situations that no one understands, but which occupy very large expenditures with little useful results and often very unfavorable consequences (described as "nitrogen situations").

2.2 Nitrogen situations

To each nitrogen situation, there typically is associated a (usually small) class of observers. These are individuals who have partial knowledge of the situation. If some specific case is required as an example, imagine that a hurricane is crossing the Atlantic Ocean, heading for the southern United States. Some observers are located on ships at sea. Some are on islands. Some are on the shore. Some are in planes. Some are officials of the government. Many are gatherers of data. Perhaps fifteen or more are modeling the movement of the hurricane and projecting its path. As they supply the trajectories to the television news services, the news services overlay these trajectories on the screen. They are all different, showing very different paths to the public. At most one of these paths can be correct. Very likely none of them is correct.

This is a typical example of a nitrogen situation. Another example, taking place on a much smaller time scale, is the provision of medical services to a population. A variety of potential respondents have a variety of information components relevant to the design of a health-care system. Politicians appear to believe that they can design such systems in ad hoc ways, not even asking whether scientific methods are available to design such systems.

The literature is available to record a number of examples of nitrogen situations that have been dealt with during the past few decades. Many examples are illustrated in the "Warfield Special Collection" at the George Mason University in the Fenwick Library, located in Fairfax County, Virginia. A searchable URL is found at (http://ead.lib.virginia.edu/vivaead/published/gmu/vifgm00008.xml.frame). This collection can be searched on the Internet, so no further discussion will be given here to induce an air of credibility. *What is to be emphasized here is the distinction between the oxygen situation and the nitrogen situation.* What universities teach are almost without exception oxygen situations, though they may mention nitrogen situations in passing.

2.2.1 In Summary. In summary, systems science is developed to work with nitrogen situations. After it has been applied, it will normally be true that a fallout from the work will involve numerous oxygen situations that have been defined sharply to be pursued as a consequence of the work.

2.3 Problems and Situations

Nitrogen situations typically embody numerous interrelated component problems, hence the expression "start by defining the problem" is an anachronism. Data for 43 nitrogen situations appearing in (Warfield, 1994, Appendix 5) show that the minimum number of component problems seen up to that point in time was 36, the maximum was 127, and the average number was 64. The word "problem" being reserved for these components, the word "situation" is chosen as the over-riding concept. At times, the word "system" would be acceptable in place of the word "situation", but the use of that word tends to be prejudical and should be avoided, in general.

2.4 Problematique and Graphacy

A problematique is a type of structural model produced by a group of respondents as a consequence of applying systems science, as defined in (Warfield, 2006). **[Henceforth, all references to systems science will be references to what is described in that reference. A partial justification for that choice can be seen by referring to the Preface in that book.]** Table 2 lists a small sampling of titles of problematiques that have been produced for various respondents. Two types of problematiques are produced. Type 1 shows how some problems make other problems more severe. Type 2 shows how some categories of problems make other categories of problems more severe.

Readers who are unfamiliar with problematiques are invited to examine Appendix D in (Warfield, 2002.) It includes 17 problematiques from a wide variety of applications in different countries carried out by different practitioners.

People do not know intuitively how to read problematiques (Perino, 1999). Technocrats have been found to be prone to believe that they do. This is hazardous because they may misread them and place confidence in their misreading, taking actions that are based on faulty interpretation. Hence one of the many learning outcomes from a systems science program is the development of the ability to read structural graphics. There is no good term known for this, but the word “graphacy” is somewhat like “literacy” and the frequently-used British term “numeracy”.

Table 2. List of some published problematiques:

Source of problematique	Title of problematique and location where developed	Where is it published?
John N Warfield	Policy research, Type 1, Virginia, USA	UCT&B, page 204
John N Warfield	Policy research, Type 2, Virginia	UCT&B, page 213
Scott M. Staley	Analytical power train, Type 1, Michigan	HIM, page 305 and 306 and UCT&B, page 215
John N. Warfield	Analytical power train, Type 2, Michigan	UCT&B, page 216
Benjamin Broome and staff of the Joint Chiefs	Joint operations, Type 1, Virginia	UCT&B, page 218
John N. Warfield	Joint operations, Type 2, Virginia	UCT&B, page 219
Benjamin Broome	Problem-solving groups, Type 1, Virginia	UCT&B, page 224
John N. Warfield	Problem-solving groups, Type 2, Virginia	UCT&B, page 225
Benjamin Broome	Peace-Building in Cyprus, Type 1, Cyprus	UCT&B, page 226
A. R. Cárdenas and C. Moreno	Industrial development, Type 1, Nuevo Leon, Mexico	UCT&B, page 227
Carol Jeffrey	Gender issues, Type 2, Liberia, West Africa	UCT&B, page 228
Carol Jeffrey	Disarmament and demobilization, Type 2, Liberia	UCT&B, page 229
Robert James Waller	Pump manufacturing, Type 1 Waterloo, Iowa	ASOGD, page 395 and UCT&B, page 230
Roy Smith	The Redemptorists–church, Type 1, England	UCT&B, page 231
Roy Smith	Help desk redesign, Type 1, England	UCT&B, page 232
Scott M. Staley	Manual transmission gear design, Type 1, Michigan	UCT&B, page 233
A. N. Christakis and H. C. Alberts	Smart munitions, Type 1, Virginia	UCT&B, page 234
John N. Warfield	Computer and information systems industry, Virginia	ASOGD, page 312
A. N. Christakis and H. Sokoloff	Shared governance in PA school districts, Virginia	ASOGD, page 323
A. N. Christakis and Bill Gordon	National Marine Fisheries Service, Virginia	ASOGD, page 359
A. N. Christakis and H. C. Alberts	Department of Defense program management, Virginia	ASOGD, page 376
A. N. Christakis and W. Gasparski	Design culture in higher education, Type 2 Chios island, Greece	ASOGD, page 521

HIM = Handbook of Interactive Management (1994) ASOGD = A Science of Generic Design (1994),
UCT&B = Understanding Complexity: Thought and Behavior (2002). All are books. Please see the References section of the paper for detailed citations.

3 Adapted Scientific Tradition

Science and technology seldom proceed apace. As Sir Geoffrey Vickers observed (Vickers 1980), Japan had magnificent steel around the year 1200, long before metallurgy had advanced to the point where an understanding of the science had been reached. As Vickers observed, “throughout almost the whole of human history, technology has progressed with an uncanny ignorance of the scientific principles which were guiding it”.

Nonetheless, it is certainly clear that the 1700s produced scientific results that gave science the lead on technology for a certain period of time. The result of this relatively brief lead was the flowering of a magnificent array of technology. The mid 1940s and early 1950s saw another brief era of scientific discovery which, once again, gave support to a massive technological explosion that is still underway.

Markets take over and induce momentum which eclipses scientific exploration for years or perhaps decades. It now seems, however, that a certain type of situation, lying in the Domain of Complexity, colloquially called the “nitrogen situation”, is not yielding to technological momentum. Many such situations arise in today’s world. Several hundred of them have already experienced the application of systems science. It is time to bring this science into higher education. To do this, the scientific tradition must be honored. But it must also be adapted, not by leaving out parts, but by strengthening those parts that cannot be carried out by the lone individual in the laboratory, but rather require individuals working together.

Because of prevailing confusion between what is theory and what is science it is necessary to review the nature of science. As described by Aristotle’s countryman (Ntinos C. Myrianthopoulos 2000):

> “Aristotle repeatedly pointed out that his predecessors’ work and conclusions were often marred by insufficient observation. He himself, after a remarkable analysis of the reproduction of bees, states that he cannot arrive at certain conclusions because ‘the facts

have not yet been sufficiently ascertained. And if at any future time they are ascertained, then credence must be given to the direct evidence rather than to the theories; and to the theories also, provided that the results which they show agree with what is observed.'" This, indeed, is the principle upon which his work is based. It is also the definition of the scientific method, which was later broadened in scope, especially by Bacon, and by and large constitutes the basis of the scientific method we practice today. Note the subtle yet critical point: Aristotle does not say "the results prove the theory," but "the results agree with the observations."

Today we take this reasoning for granted, that science proceeds and progresses not by proving hypotheses, but by disproving them. If the observations do not agree with a hypothesis, we shelve it; if it does agree with a high enough level of certainty and consistent repetition of the results, we accept it, but we can never prove it."

Then it is appropriate to review the details of the scientific method by calling on America's most thoughtful scholar of science, Charles Sanders Peirce whose work, described in the Collected Papers (1958-1966), reviewed the foundations of science as follows:

65. There are in science three fundamentally different kinds of reasoning, Deduction (called by Aristotle {synagögé} or {anagögé}), Induction (Aristotle's and Plato's {epagögé}) and Retroduction (Aristotle's {apagögé}, but misunderstood because of corrupt text, and as misunderstood usually translated abduction). Besides these three, Analogy (Aristotle's {paradeigma} combines the characters of Induction and Retroduction. (From 10. Kinds of Reasoning)

Book I, Chapter 2, Sect. 65.

Abduction, as described by Peirce,

218...."Is merely preparatory. It is the first step of scientific reasoning, as induction is the concluding step. Nothing has so much contributed to the present chaotic or erroneous ideas of the logic of science as failure to distinguish the essentially different characters of different elements of scientific reasoning; and of the worst of these confusions, as well as one of the commonest consists in regarding abduction and induction taken together (often mixed with deduction) as a simple argument." [From 8. Abduction.]

Book II, Chapter 3, Section 8.

Eventually Peirce chose to stay with the term "Abduction":

Abduction, in the sense I give the word, is any reasoning of a large class of which the provisional adoption of an explanatory hypothesis is the type. But it includes processes of thought which lead only to the suggestion of questions to be considered, and includes much besides.

Footnote, Book III, Chapter 2, Section 2.

3.1 Joint hypothesis construction

While in the older days the individual genius might be able to dedicate attention to the formulation of a proposition based on extensive observation, today a situation may involve so many variables that no one may have an adequate grasp of the situation. Hence no reasonable hypothesis may be formulated by a single individual. Could it be possible that a sensible hypothesis could be formed by a collaboration of multiple observers?

The answer to this question is affirmative. The evidence has been accumulated over decades and now stands clear, accompanied by a variety of supporting collateral scientific data. Keeping in mind that a hypothesis is not intended to furnish the "answer", but rather is intended to point the way to inductive resolution of a situation, we will find that the following events have repeatedly occurred in the following sequence:

- Groups have collaborated in working on problematic situations that no individual member understood

- Data collected from the groups using the Nominal Group Technique (NGT) (Delbecq, et al 1975) reveal that the number of component problems in these situations far exceeds what behavioral studies show are within the limits of the span of immediate recall of the human memory
- When the views of members of the group on relative importance of the component problems are solicited, it is clear that there is little correlation among their views, illustrating the wide divergence of viewpoints before the process of joint hypothesis work begins (this phenomenon being called “Spreadthink”) (Warfield 1995)
- Joint activity with computer-assisted structuring using Interpretive Structural Modeling (ISM) (Warfield 1976) produces a structure called the “problematique”
- A problematique consists of a collection of consensus-generated relationships among selected component problems in the problematic situation
- A problematique is a tightly-connected logic structure based on De Morgan’s theory of relations, cited by C. S. Peirce as a major theoretical development
- A problematique furnishes insights into how the problems are interrelated, suggesting strategies for resolving the problematic situation which correlate with the consensus viewpoints of the members of the group

3.2 The problematique as structural hypothesis

The problematique meets all the conditions that one would expect of a hypothesis. It is based on beliefs as represented by the cumulative, aggregated, integrated perceptions of the members of the group as they have been generated, clarified, discussed, and finally voted upon by majority viewpoint of the members, using NGT. **Moreover, with computer help using ISM, the consistency of the collective relationships has been assured as a consequence of what is known as Harary’s Theorem of Assured Consistency, which is incorporated in ISM.** Thus the problematique represents a consistent logic structure reflecting the best available information gathered by a set of observers, from which viewpoints that could not meet the test of majority acceptance after thorough discussion have been excised. **The individual who has spent a lifetime**

in the throes of oxygen situations is conditioned to presume that a problematique should represent a solution rather than a hypothesis. But steady application of long-worked out equations and processes from the past are not what is being dealt with in the nitrogen situations!!! In these situations, one is instead in the same position as the early investigators whose work furnished the resources that now make up the bulk of fixed resource for practitioners to apply existing algorithms to gain the "single answer".

As a consequence of this work, the theory implied by the problematique can be articulated, and a program can be laid out to test the theory to see if the structural hypothesis can be verified. Normally this test coincides with what would be considered to be action to resolve the problematic situation: the recipe for its resolution. **To the extent that the hypothesis is flawed, learning will take place along the way.**

This means that each problematic situation, in effect, becomes the basis for a mini-science in its own right. This should not be very surprising, because each of them constitutes a unique situation.

3.3 Laboratory Component

A critical component of the systems science program is the laboratory. Laboratories have always been part of scientific discovery. The invention of the systems science laboratory must adapt the concept to the purposes of systems science. Before taking on that challenge it is appropriate to review the situation for single-observer science, keeping in mind that applications of systems science are typically and almost invariably, multiple-observer applications, requiring that observers collaborate in whatever is done, as discussed already in connection with the formulation of a structural hypothesis.

3.3.1 Single-Observer Science and the Laboratory. Science, in the 18th and 19th centuries and, to some extent earlier, was largely a product of single observers, working in laboratories. Confined in modest architectures, working with limited equipment, the individual scientist could lay out experiments, observe the results, make calculations, make changes, do more calculations, iterate, make discoveries, and publish.

With this architecture-based prototype, numerous individuals gained recognition, as did their work, and natural science came into existence as a proper subject of study in higher education. As it did so, laboratories began to be incorporated in universities, because it was not possible to study chemical reactions adequately with a pencil and paper, except up to a point.

3.3.2 Single-Composer Music and the Orchestra. The distinction between oxygen and nitrogen situations has a partial analog in music as it relates to the geometry of the working environment. Working at the piano, the great composers of the 18^{th} and 19^{th} centuries wrote and rewrote their symphonies, sonatas, etudes, and waltzes. As they did so, ensembles began to play them. Teachers began to teach them. Universities began to develop larger and larger spaces where both individuals and ensembles could practice, i.e., learn to play solos, duets, trios, quartets, orchestra or band compositions, because it was not possible to study these pieces adequately with a pencil and paper alone, or instrument alone, except up to a point.

With the architecture-based prototypes, universities vied for fine arts students, creating also spaces for young artists, with classes involving easels, paints, and charcoal. *Space is created to fit the necessity of practice.*

3.3.3 Single-Observer Science as a Conceptual Fixation. Because of the centuries-long experience of science as a phenomenon associated with a single observer (even to the point of the portrayal of Dr. Frankenstein with the handicapped laboratory assistant Igor, and with Dr. Jekyll and Mr. Hyde in literature; the lasting names of individuals from many countries, e.g.,Faraday in England, Lavoisier in France, Pavlov in Russia, Hertz in Germany, and Fermi in Italy) the idea that *all* science is single-observer science, and that whatever conditions apply to any science would of course be those of single-observer science, would appear to be part of a conventional clanthink posture of this generation (i.e., all members of a body of people believing the same thing, even though it is wrong–like a belief that the earth is flat).

The natural point of view would then entail the idea that a laboratory would be set up, e.g., in political science or sociology, but this is readily avoided by stating that “the world is the laboratory”, and that statistics is the natural mathematics, so that by simply taking statistical data from a census or other external sources, and writing papers, one has followed the presumed practice of the single-observer science. In this way, the clear folly of attempting to pursue systems learning with a single observer in a university laboratory along the lines of Faraday is abruptly abandoned, never to be raised in polite company. The possibility that the single-observer model should have been dispensed with for systems science at the outset as a *non sequitur* may have escaped purview.

3.3.4 Ubiquitous Single-Observer Science. Fortunately for the legacy of Sir Isaac Newton, gravity is essentially ubiquitous; ubiquitous because it is found everywhere on earth and, as far as we know, on the moon and elsewhere in the solar system; essentially, because the so-called “gravitational constant” is not really a constant, but rather varies sufficiently that (as was well-understood by the American logician Charles Sanders Peirce) its variation enables one to navigate near the seashore, based on the knowledge of that variation, with the aid of measurements of the motion of swinging pendulums. **The concept that is generalizable is that observations relevant to the nitrogen issues stem from observers located at different points in cognitive spaces (mental life trajectories), which is part of the reason that groups are necessary to attack such issues and to formulate hypotheses to proceed to work with them.**

Because of similar ubiquity of other natural sciences (now taken for granted, and not even whispered about in academic halls), jet travel is possible, students can study in various countries and return to their home countries to practice what they learned about science and engineering and, in general, the natural world seems fairly well organized.

Not only are the results more or less space-independent, but they are also more-or-less time independent, unless of course you are traveling along with Albert Einstein. If you leave the USA to go to London, you do not expect time measurements or the laws of motion to change significantly while enroute, and you expect that a microsecond, a millimeter and a microampere will be about the same when you arrive in London as when you left New York.

Single-observer science is ubiquitous in the sense that the conclusions contained therein are essentially space- and time-independent in applications, which accounts for the portability of scientific data in applications and enterprises. This explains even the growth of multi-national corporations, who rely on the ubiquitous properties of single-observer science for their every-day business operations. No wonder there is a market for people with education in the single-observer sciences!

3.3.5 Parsimonious Single-Observer Science. One hears such terms as “hard science” and “soft science” where the former typically refers to single-observer science and to natural science. Less frequently one heard the term “pure science” referring to natural science. The connotation has often been to imply that for natural science the measurements, such as that of time down to many decimal places, are so precise that one seldom has a problem with precision, and certainly errors are unlikely. The social sciences, it is said, are “soft” and much more difficult, much more prone to error.

Yet, when Dr. George J. Friedman was asked to comment on the origins of failures in large-scale technical systems from his position as chief technical officer of Northrop Corporation, he unhesitatingly offered two main reasons (Warfield 2002):

- *the most important reason*: errors in formulation of the system models, stemming from overburden of the cognitive apparatus of the modeling personnel, in spite of the fact that they had outstanding education and outstanding computer equipment
- *the second most important reason*: failure of the technicians to follow the instructions of the engineering designers

These can be called *cognitive overload* and *communication breakdowns*.

In expanding on these reasons, Friedman emphasized that almost all of the equations of physics have six or fewer variables. He stated his belief that when the number of variables in a situation exceeds that number, the scientist or engineer is likely (unwittingly) to omit from consideration factors which would overtax the cognitive capacity of the designer mind of the human being (Warfield 1988).

Single-observer science is parsimonious in terms of the number of factors that can be properly observed and taken into account in model formulation and empirical testing. By no means does this prevent individuals from forming many-variable models, from presenting them, from showing results of computations, and from offering interpretations and predictions. Nonetheless, when the time arrives for comparison of results with predictions, there is typically an awesome silence occasioned by the large discrepancies between model results and empirical evidence.

3.3.6 The Laboratory is Where Complexity is Replaced by Understanding. The systems science, practiced through what is called The Work Program of Complexity (WPOC), has, as its central purpose, the generation of sufficient insight to enable the respondents who begin with only fractional understanding of the nitrogen situation, to emerge ultimately with a structured understanding of that situation.

The WPOC itself has two major parts: Discovery and Resolution. The Discovery often reveals enough insight that respondents feel they can proceed to Resolution. When a proper systems science program is set up, budgets should allow for adequate followup.

Historically, many respondents have gained enough understanding from the early part of the WPOC, to revert to their ordinary ways; perhaps under pressure of time and resources from their organizations. Rather than continue with the science they lapse into the “oxygen mode”. If the respondents have the patience to carry forward from beginning to end, the result is expected to include **an action design**, for carrying through to resolution of the nitrogen situation. **An example consists of the strategic system design of the Ford**

Motor Company C3P enterprise-wide information system (Staley and Warfield, 2007), the design of which followed precisely the practices laid out in the systems science (Warfield, 2006).

3.3.7 Strong Spatial Scanning Facilities. The common practice in too many situations involving attempts to resolve complexity appears to be to use small displays, whether they be computer screens (shared or not shared), reports, flip charts, or other modestly-sized devices. What is required, as several decades of experience has shown conclusively, are large (e.g., 30 feet long or more) wall displays, showing the structures of relationships, with large fonts (e.g., capital letters with size 72 fonts), so that the powerful scanning features of the human eye can be employed together with the ability to converse with one another in small groups. This is an essential feature of the laboratory for a systems science program. In one of the most successful applications, several adjoining rooms were used, so that displays could be kept for several days.

Rooms for such facilities should be of two types. One type is called the "situation room", which is used for group description and design work. The other type, called an "observatorium" (Warfield 1995) is used for semi-permanent displays, used for educational purposes or to amend already-produced structures to show progress or to update structures as time passes, or both. Various literature exists and videotapes are available showing work in practice in the Fenwick Library in the "Warfield Special Collection".

Figure 1 illustrates an example of a situation room with a facilitated workshop in progress, using the systems science in the manner described here. In this instance the facilitator is the only one standing, and a structural model can be seen on the wall at the upper right of the picture.

Figure 1. An example situation room with an Interactive Management Workshop in progress. Notice the wall displays, the facilitator (standing) at work, and the structural model on the wall at the upper right.

Photograph courtesy Parker-Hannifin Corporation Aerospace Group.

This particular workshop benefited from the availability of a very experienced four-person team shown in Figure 2. This team was augmented with local staff from the client who helped with local arrangements and various special tasks typically required during the conduct of workshops, as described in the *Handbook of Interactive Management*.

Figure 2. A facilitation team; left to right: Philip Ernzen (retiree from Ford Motor Company), Brenda Ramirez and Carmen Moreno (faculty members from the Instituto Tecnologico y de Estudios Superiores de Monterrey–ITESM) and Benjamin Broome (Professor from the Arizona State University, Tempe). Notice wall display of categorized elements behind the facilitation team.

Photograph courtesy of Parker-Hannifin Corporation Aerospace Group

4. The Horizons College Flow Model

The Horizons College houses the systems science program. But the program cannot be defined simply by discussing the Horizons College. To define the program, it is necessary to see it as part of a larger picture that includes the institution to which it is joined as an orthogonal extension, and the external respondents which constitute its yet-to-be-revealed and constantly changing service base: those who are beset by nitrogen situations, and who have come to appreciate that normal methods will not enable them to resolve these situations.

The Horizons College flow model is shown in Figure 3**.** The university is represented by an oversimplified model consisting of two colleges: the University College (which involves an aggregate of the arts and sciences) and the Professional College (which involves an aggregate of other parts of the institution including such diverse components, which may or not be present, as the medical school, the engineering school, the business school, the agriculture school, the nursing school, and others). The reason these are aggregated is that the Horizons College will require from time to time access to resources drawn from across the university in as timely a way as possible, and as part of the contract, the institution will have to agree at least to provide a very competent interface executive who will administer an interaction budget coming from the Horizons College, which can be drawn upon to access consulting resources from other parts of the university.

4.1 University Consulting Practices.

For those unfamiliar with university practices, it is noted that most institutions allow one day a week of consulting to their faculty as long as two conditions are satisfied: (1) the consulting does not interfere with their normal assignments and (2) the consulting is of such nature as to enhance their competence in their university positions. Since the work of the Horizons College is almost always likely to satisfy the second

	Horizons College	University College	Professional College	Respondents
Horizons College	• Systems Science Foundations • Work Program of Complexity • Managing the Unmanageable	Basic course in systems science; professional services, if requested	Basic course in systems science; professional services, if requested	Professional services in applying the Work Program of Complexity to Nitrogen Situations
University College	Arts and science instruction; consulting assistance when requested			
Professional College	Consulting assistance when requested			
Respondents	Participants in applying the Work Program of Complexity to Nitrogen Situations			

Figure 3: Flow Matrix. The flow is from the organization on the left to the organization at the top. For example, the Professional College provides "consulting assistance when requested" to the Horizons College. The text provides more details on the flows that are aggregated in this Flow Matrix.

of these conditions, it will be the responsibility of the interface executive to work with administrators in the other parts of the institution to satisfy the first of the conditions.

Not only will consulting be required from time to time to assist in various ways that cannot be anticipated until the specifics of nitrogen situations come into view, but certain course work may also be helpful as will be discussed next. The possibilities for conflict in course work are great, because the requirements for quality control in what is offered in systems science courses are stringent, and normal courses will not do. Substantial negotiation will be required, and The Horizons College must have total control over what is offered in its course work.

4.2 Respondents

Respondents from many areas of society have nitrogen situations that have not been resolved. Anachronistic governments follow the same practices that they have been following throughout history. These practices regularly demonstrate their inappropriateness for resolving the nitrogen situations of today. Yet the outmoded practices continue, and there is so much vested interest in continuing them that there is little likelihood of any change any time soon. This is why The Horizons College has become such a critical necessity in society.

Several modest efforts have already demonstrated the existence of a significant market for the work of a Horizons College. These efforts, carried out at the City University (London, England), the former Defense Systems Management College (DSMC, Fort Belvoir, Virginia), University of Virginia (Charlottesville, VA), Instituto Tecnologico y Estudios Superiores de Monterrey–ITESM (Monterrey, Mexico), and George Mason University (Fairfax, VA), have demonstrated conclusively that there is an abundance of work to be done. At the same time, institutional factors have also demonstrated that unless there is a strong and unassailable institutional commitment and priority (including a recognized line-item in the university budget) around the work it cannot survive for some of the reasons cited in previous papers about obstacles to initiating and sustaining such programs. These reasons, summarized partly as thematic vulnerability and virtual conspiracies, will suffice to destroy the most carefully built and nurtured programs if they are not given institutional support comparable to what is extended to historically embedded programs who do not even require respondents!!

4.3 Courses Provided to Others

The Horizons College may provide courses for other parts of the university if time and personnel permit, and if such courses are desired. A basic course in systems science is appropriate. Such a course would involve the three fundamentals of systems science, which are the same as the fundamentals of all science (Warfield 2006): the human being, thought about thought, and language. Because of its fundamental nature, a course of this type would ultimately encourage some changes in the curricula of the Professional College, since the courses offered are not founded in fundamentals, in general. Language is typically ad hoc, of the type that arises out of necessity in fields that are rapidly growing such as the computer area, involving devices from solid state physics where the devices were being invented almost as fast as the physics were being discovered; and where miniaturization was taking place rapidly requiring new names for smaller and smaller components. In medicine, the study of genes occurred so rapidly and was thought to provide the answer to many diseases, only to find that the mystery of proteomics offers a whole new host of challenges of much greater mystery than that of genetics. There is little or no time for careful and systematic choice of language to keep up with the discoveries in these fields.

In the high-tech areas, there was almost no room for study of the behavioral sciences, and often there was outright denial or interest in what was found in these sciences. So when President John F. Kennedy wanted to promote the Bay of Pigs adventure, he asked his brother Robert Kennedy to sit in on the group and try to make sure that it reached the “right” decision. As Professor Graham Allison of the Kennedy School of Government documented in detail (Allison 1971), the behavioral pathology identified by Irving Janis as “groupthink” (Janis 1982) was active at the highest levels of government. As seen in retrospect, the abjectly ridiculous decision to go ahead with the decision to invade Cuba, at least taught a lesson to President Kennedy who did not repeat the same mistake with a group when the Cuban Missile Crisis had to be dealt with in a short time.

Behavioral pathologies of the human being must be among the major studies in the Horizons College. The way in which the process designs chosen for carrying out The Work Program of Complexity amplify the creative talents while circumventing the majority of the behavioral pathologies must be understood, in order to insulate the uninformed from substituting oxygen methods that have no preventive power from being substituted for them.

4.4 Internal Learning in the Horizons College

Internal learning in the Horizons College can be loosely divided into two parts:

- **Scientific base**. This involves studying the triadic scientific foundations of systems science in detail: the human being, thought about thought, and language; the design of processes to take advantage of what is known about these foundations; The Work Program of Complexity (WPOC); the products that are produced when the WPOC is carried out; the roles that are involved in carrying out the program; the complexity metrics that are generated when these roles are applied in carrying out the WPOC; the products that are produced; the insights that are developed from these products; managing the unmanageable; and the availability of library resources.

- **Workshop-related activity.** The title "Workshop" is given to a gathering where staff of The Horizons College direct the carrying out of The Work Program of Complexity with a group of people representing a class of respondents. Often, in the literature, such a workshop will be described as an "Interactive Management Workshop" or "IM Workshop". Included in the learning program of The Horizons College will be the preparation of proposals for carrying out The Work Program of Complexity, the study of the nature of facilities for carrying out the WPOC, group facilitation; the broker role; the disruptive agent; requirements respondents must satisfy; data to be collected, analyzed and retained; report preparation; and the observatorium option. Also included will be the conduct of Workshops for respondents, interpreting results for respondents, preparation of reports for respondents, and publishing of accumulated scientific data on workshops to add to the literature of systems science.

The observatorium (Warfield 1996) is a concept that surfaced since the *Handbook of Interactive Management* was published (Warfield and Cárdenas 1994). The basic idea is to provide a facility to sustain the learning and graphical communication of results from beginning to end of a nitrogen-resolution program. The work of a group in a workshop produces an extensive set of graphical products. Others not involved in that work will need the benefit of the insights obtained from the graphics. It is not reasonable to burden them with the small-scale condensed graphics so commonly used in oxygen situations. To pay for real estate to display results, and keep them up to date, is a small price to avoid the often extremely large costs (possibly in lives as well as dollars) which can occur because of misunderstandings occasioned by poor communication in nitrogen situations.

The wise manager will take note of this and act accordingly.

4.5 Workshop-Related Activity

It is intended here to discuss both workshops and the scientific base, but most of the emphasis will be on the scientific base. The workshop activity has been discussed in great detail in the *Handbook of Interactive Management* (Warfield and Cárdenas 1994). Some new things have been learned since that book was published which, incorporated with Interactive Management, produce what is now called The Work Program of Complexity. Additions are mostly discussed in discussing the scientific base. What can be added is the fact that many more applications have been carried out since that book was written (although it lists more than a hundred). As a result, it can be said that there is about a 98% success rate, as measured by the respondent opinion of results. It can also be said that the principal cause of the very few instances of process breakdown is the presence and action of what is called a disruptive agent. The disruptive agent might be explained by what is called the Dunning-Kruger Effect (Kruger and Dunning 1999).

4.5.1 The Dunning-Kruger Effect. This effect is described by the authors as follows:

> "Across 4 studies, the authors found that participants scoring in the bottom quartile on tests of humor, grammar, and logic grossly overestimated their test performance and ability. Although their test scores put them in the 12th percentile, they estimated themselves to be in the 62nd."

In summarizing with rough language, not-so-bright people thought themselves very bright, while bright people tended to underestimate their competence.

If this effect turns out to be present now and then in small groups, a disruptive agent may be permitted to cause a group process to flounder, because those who are much more knowledgeable may underestimate their own judgment, while allowing the individual who is much less competent to dominate the situation.

There is no conclusive evidence to support the idea that this was the cause of the 2% of the failures. But the fact that the processes worked 98% of the time, and didn't work only when there was a single disruptive agent, might indicate that there was some pathology at work, in the person of the voluble and non-cooperative disruptive agent, which went uncorrected by the facilitator-broker combination. **To understand the 98% figure, one notes that it depends on the meaning of "success". This term was given five distinct definitions in (Warfield and Cárdenas 1994). Before a workshop is begun, a client chooses which of the five definitions is to be used to measure success. In this way, both the practitioner and the client have a basis for understanding what is to be accomplished. In the very early days it was believed that the most demanding definition would be chosen. Instead what was found was that the definition almost always chosen was the least comprehensive: "Level 1: Learning more about what is involved**

in approaching the issue (the lowest level of success)" [page 25, Chapter 3, IM Success Levels). This common choice offers some evidence to support the view that the cognitive partition–i.e., the oxygen-nitrogen split–reflects the idea that no one really understands the nitrogen issues, and what is being sought is insight, as distinct from final solution.

In any case, it is the joint responsibility of the broker and the facilitator to sense that disruption is occurring, to stop the group process, remove the disruptive agent, and continue. (The broker role is explained in the *Handbook of Interactive Management*).

5 Triadic Scientific Foundation for Systems Science

The foundation for systems science lies in the triad of the human being, thought about thought, and language **(Warfield 2006)**. As mentioned in Section 1 above, the details of linguistic integrity with colloquial referents are well in hand, but are unique to systems science and its application, hence become part of the learning experience of a systems science program. Fortunately this portion of the program is not difficult to learn. The other two aspects, on the other hand, are more formidable.

5.1 The Human Being

The role of the human being, both as a scientist and as a resolver of problematic situations traditionally is suppressed in the literature except, perhaps, as a heroic figure or as an unusual denizen of the laboratory accompanied by a deformed associate.

Nonetheless a few philosophers of science, such as Charles Sanders Peirce and Karl Popper have emphasized the fallibility of man. It is, therefore, no great stretch to connect the human being as scientist and as individual engaged in attempts to resolve problematic situations to a fallible actor. The description of a fallible actor grows rapidly when the literature of psychology and sociology is consulted. This literature sets forth what is readily describable as behavioral pathology when involved in attempts to resolve problematic situations. Given these readily verifiable facts, it is astonishing that so much of the contemporary literature bypasses altogether these behavioral matters. Systems science necessarily must encompass this literature. More specifically, it must incorporate this literature and specifically must do so in the design of processes through which nitrogen situations are described and designs are constructed to resolve them.

At the same time, the well-known and usually presumed creative talents of the human being must also be taken into account and nurtured. Like the fallible nature of the human, what is known about creativity is also frequently suppressed. Instead it seems that the human is often looked upon as capable of infinite creative powers and not susceptible to any measure of fallibility. While these visions of the human being are certainly favorable to massive publication, they carry little that is favorable to the resolution of nitrogen situations.

5.1.1 Behavioral Pathologies. Many of the behavioral pathologies have been discussed at length in the literature, along with the means of bypassing their effects through careful design of processes (Warfield 1994, 2002, 2006) (Warfield and Cárdenas 1994). Accordingly, only a brief representation will be given here, consisting of the summary in **Table 3** of key investigators with their topics and some related overview philosophers. Table 3 is intended to emphasize the necessity of giving great prominence to this topic in the Horizons College. Similarly, the conditions to encourage creativity have been discussed, and the weaving together of conditions favorable to combining creative behavior with the suppression of behavioral pathologies has been discussed extensively.

Table 3. Part 1. Some Key Investigators and Behavioral Topics	
Investigator	**Topic**
Allison, Graham T	Documenting groupthink in decision-making leading to the Bay of Pigs event.
Argyris, Chris	Documenting high-level mismanagement of critical information in organizations, as well as failure of management to understand what is important, or even to know that they don't know how to determine what is important
Bales, R. F.	Illustrating how to record and categorize micro behavior of individuals working in groups, and to build profiles of individual behavior
Boulding, Kenneth	Describing three principal reasons for poor intellectual productivity
Delbecq, Andre L.	Designing a process to circumvent certain behavioral pathologies
Downs, Anthony	Predictability of bureaucratic behavior
Dunning, David	The Dunning-Kruger syndrome, misjudging self-competence
Etzioni, Amatai	Explaining societal overload in these days
Gustafson, D. F.	Collaborated with Andre Delbecq (above)
Janis, Irving L.	Scientific description of groupthink
Kapelouzos, I. B.	Discovering the effectiveness of ISM as a learning process
Kluckhohn, C.	Defining "culture"
Kruger, Justin	See "Dunning, David" above
Lasswell, Harold	Designed working environments to display necessary information
March, James	Showing that research on organizations is feasible
Mayer, John	With Peter Salovey, proposing the concept of "Emotional Intelligence"
Miller, George A.	Explaining the limitation on immediate recall in short-term memory
Moynihan, Daniel	Explaining the unwillingness of leadership to admit being overwhelmed with complexity
Osborne, Michael	Importance of failing to interrupt creative thinking while it is in process
Perino, G. H.	Discovering inability of high-level managers to read and interpret structural graphic presentations, and their propensity to make unwarranted assumptions concerning systems processes and practices
Salovey, Peter	See "John Mayer" above
Tuckman, B. W.	Clarified and defined the typical pattern of unregulated group process
Van de Ven, A. H.	Collaborated with Andre Delbecq
Vickers, Geoffrey	Emphasized the distinction between physical and human systems
Warfield, J. N.	Discovered the ubiquitous nature of "spreadthink" and how to overcome it with designed processes

Table 3. Part 2. Overview Philosophies Concerning Behavioral Topics	
Investigator	**Topic**
Argyris, Chris	Documenting high-level mismanagement of critical information in organizations, as well as failure of management to understand what is important, or even to know that they don't know how to determine what is important
Boulding, Kenneth	Describing three principal reasons for poor intellectual productivity
Bunge, Mario	Measuring social sciences against philosophical criteria
Etzioni, Amatai	Explaining societal overload in these days
Foucault, Michel	Stressing the critical importance of discursivity, offering a prescription for how to write history, which has been incorporated in systems science as a means to write the history of recent events
Kluckhohn, C.	Defining "culture"
March, James	Showing that research on organizations is feasible, and pioneering such research
Moynihan, Daniel	Explaining the unwillingness of leadership to admit being overwhelmed with complexity
Vickers, Geoffrey	Emphasized the distinction between physical and human systems

5.2 Thought About Thought

As is well known, Aristotle (circa 350 BC) introduced inference into the history of human thought through the syllogism: a three-statement sequence, where a conclusion is drawn from two prior statements.

More than 1400 years after Aristotle, Abèlard could replace the three-statement sequence with a single statement, expressed in terms of antecedent and consequent, laying a linguistic basis for the application of George Boole's algebra, which would appear over 700 years later.

While Boole's algebra provided a symbolic base for expressing inference on a much broader scale than that given by Aristotle, it drew very little support in terms of practical applications because its linguistic appeal was very limited. In the same time period, Augustus De Morgan discovered and published the theory of relations, which laid a conceptual basis for creating very large structures of relationship, but this theory also drew very little support in terms of practical applications, for the same reason. **Few so-called "systems theories" even today incorporate or even mention De Morgan's work, while emphasizing the critical importance of relationships among the parts!!**

More than a hundred years after Boole and De Morgan, the graph theorist, Frank Harary, discovered a Boolean reachability matrix and an equation that encapsulated the combined essences of the work of Aristotle, Abèlard, Boole, and De Morgan, taking advantage of the matrix theory of Arthur Cayley, adapted to Boolean algebra.

5.2.1 Interpretive structural modeling (ISM). With the benefit of Harary's apparatus, Warfield developed a process called "Interpretive Structural Modeling", shortened to "ISM" (Warfield 1976, 2003). With the ISM process, it became possible for groups of people to engage together with a computer to construct **consistent logic patterns of interaction** among sets of problems.

5.2.2 Problematiques. One type of pattern of interaction came to be labeled "problematique". This nomenclature fits very well into the concept promoted by **the great twentieth-century French scholar of the history of thought,** Michel Foucault, as described by Rabinow (Rabinow, 1984), who expressed the point of view that history ought to be written as a compound of the recordables of the time, together with an analyst's perspective on the problematique that the actors were striving to resolve by whatever historical events they undertook to precipitate.

Bringing history into immediacy, groups have been applying ISM to problematic situations of substantial variety since about 1974 when ISM was first announced. Table 1 has illustrated several examples of these situations.

5.2.3 The Aristotle index of complexity. Recently it has been discovered that a measure of complexity called the "Aristotle Index" can be computed by combinatorial analysis of a problematique. This enables different situations to be compared based on the relative size of the Index. When problematiques are applied to gain insights into system designs, it has been found that designs having lower values of Aristotle Index tend to be preferable to those with higher values. Thus concepts that are well over 2000 years old, **can** provide insights into issues of importance today.

5.3 Complexity Metrics

While the Aristotle Index is one example of a complexity metric, a variety of other metrics of complexity can be computed from the data aggregated as the Work Program of Complexity proceeds. These various metrics are highly useful in gaining insight into nitrogen situations. Since these metrics have not been discussed at length, they will be discussed in some detail here. The discussion relies on an understand of the two methods that are required in carrying out the Work Program of Complexity: The Nominal Group Technique (NGT) (Delbecq, et al, 1975) and ISM. The metrics relate also to the study of cybernetics: "control and communication" involving jointly people and machines.

The **twentieth-century** literature on cybernetics can be dated from 1948. The modern literature on systems dates from about 1955. **Earlier, the concept of cybernetics dates back to Jan Maria Ampere, who introduced the term as a science on governance and control in sociopolitical and societal systems.**[2] The literature of complexity dates largely from the year 1970, trailing the beginnings of the modern literature on systems by about fifteen years. These three concepts form a set of related ideas, and have spawned sets of associated communities with partially overlapping memberships. The substantial overlap among the basic ideas warrant their integration into a consolidated science.

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[2] For this comment, I am indebted to an anonymous reviewer, who recalled that this information was published by Arthur G. Mihram in *Cybernetica* journal in Belgium some years ago.

That they have not been merged into a single, coherent science can be attributed in part to differences related to human behavior which, in turn, involve the notion of what constitutes complexity. The conflicting perceptions can be reduced essentially to two perspectives: the natural science perspective and the human science perspective.

The measurement of complexity from a natural science perspective is essentially impossible, in part because of the wide variations in types of systems to which the property of being complex would be attributed. The measurement from the human science perspective is quite feasible, and distinctly useful.

Since definition of terms is, in essence, arbitrary, there appears to be no justifiable scientific reason to persist with the natural science perspective; **its dominance in the literature notwithstanding**. On the other hand, there are justifiable reasons to honor the behavioral science perspective. One of the principal reasons is the asymmetric learning trait, which recognizes the vastly greater capability of the human being to assimilate information, compared with the distinctly limited capability of the human being to design systems.

Accordingly multiple ways of assigning numerical values to complexity of situations have been developed, calculated in various situations, and applied to making selection decisions among competing designs; where the insights gained by carrying out the processes that enable the metrics to be calculated have been most fruitful.

Three modern areas of interest, with associated scholarly societies, evolved during the last decades of the twentieth century, all having in common that they relate to systems involving complexity. While the beginnings of these areas are scarcely sharply defined, there are certain events or individuals that typically are referred to as markers for the beginnings of growing interest in the subject, whether warranted or not. For the new investigator, these markers help provide a time orientation.

5.3.1 Cybernetics. As mentioned, modern-day cybernetics is usually associated with Norbert Wiener and the date of 1948, which marks the year of publication of what is probably his best-known book. The systems field is variously associated with different people or events. Among biologists, the name of Ludwig von Bertalanffy marks the modern beginnings. Among engineers, the work on systems engineering by Arthur T. Hall III marks the modern beginnings. Many social scientists and philosophers would reference the Society for General Systems Research (SGSR) established by a team of several individuals. The period from 1948 to 1965 saw most of the early development take place.

5.3.2 Complexity. Nothing much was published on complexity until the 1970s. Thereafter a growing body of literature evolved. Institutions centered on complexity were developed, mostly outside of universities, with numerous meetings being held to exchange ideas, and journals were developed to publish articles on the subject. (It is easy to observe the quantity by going to the Internet, typing in the word "complexity" in a search engine, and noting the number of "hits". The reader may find It fascinating to compare the number of such hits with the numbers for other, more familiar, topics, as a kind of measure for the flurry of activity in a field of presumed considerably difficulty, with few academic programs to support such a volume of activity.)

A few articles appeared in the popular press and in newspapers that shed no light on what constituted complexity. Nevertheless the subject continued to mushroom as a topic of research and publication. It slowly became clear that there were two quite different and conflicting views of what constituted complexity (Song and Warfield 2000). Since definition is an arbitrary matter, neither could be said to be wrong. Nor could it be said that research founded on either definition was fruitless. Nonetheless only one of the two research paths provided a means of consistently measuring complexity.

The two conflicting views can be described as the natural science view, which ignores the human being and presumes that complexity is "in the system". From this point of view the widely-used (if rarely defined) term "complex system" is very meaningful, and is frequently used. From the human science perspective, the term "complex system" is a *non sequitur* that ought to be abolished from the literature, since complexity refers to a shortcoming of the human mind. The argument that is made is that if the human mind had no constraints whatever, it could learn everything instantly, and nothing would appear to be "complex". From this perspective, whatever is regarded as complex must be so regarded because of human limitations.

Hence if one studies what has been learned about human cognitive limitations and particularly about human behavior in working with large systems, it should be possible to develop measures of complexity. To do so would involve measuring the relative difficulty for the human being to gain insight into the system under inquiry. It might also be expected that the measures would be dependent upon the particular human beings that were carrying out the inquiry, since some people would, presumably, be better informed at the outset of an inquiry than others. This should not be surprising, since in virtually all areas involving design it is well established in human experience that some people are better at particular types of design than others.

5.3.3 Metrics for the system designer. The system designer often wishes to compare several different designs before making a choice. The number of ways to compare designs is often quite limited, cost being a prominent consideration. But significant insight into the relative merits of different designs can be gained if metrics (i.e., numerical measures) of the different designs can be found. The asymmetry system learning trait has been described to illustrate why the design situation is where complexity has the greatest impact on human performance. This trait is not noticed when the human being absorbs information from external sources. It is in comparing the differences in performance between absorbing and constructing information (e.g., between observing the Mona Lisa and painting the Mona Lisa) that the true nature of the asymmetry system learning trait is exposed. By placing the complexity metrics in the context of system design, the metrics appears in the most useful context.

Naive proposals have been made to use as the sole metric of complexity the number of elements in a system. This metric is not very helpful, even should such a number could be found. Compare the situation where System A has 1,000 elements, but no interactions among them; and System B has only 100 elements, but all of its elements are mutually interdependent. For System A, only 1,000 instances of concern are present, but for System B, if one adds the number of elements to the number of interactions, one gets 10,000; or ten times the number of instances of concern compared to System A.

5.3.4 Commonality of metrics across systems. It is very desirable that, whatever metrics are proposed, they should be common across systems; i.e., one can use them in any system of interest to any designer. This requires development and application of a common language and common process in order to acquire the data from which the values of the metrics can be computed. It also requires that quality controls shall be applied to the process to assure that it will have sufficient integrity that the interpretation of the metrics shall not be corrupted by bad process management.

5.3.5 Data for metrics. All designs, whether to create new systems, or to remedy defects in existing systems, can be construed as responses to sets of problems. It has been repeatedly demonstrated over decades that groups of partially-informed and motivated individuals can come together in a facilitated group and, using a process called the Nominal Group Technique (NGT), identify a set of problems (the "problem set"), clarify the set, filter the set to develop a subset of most important problems (the "selected subset") and, with computer assistance, use a process called Interpretive Structural Modeling (ISM), to develop a logic pattern called the "problematique" of the system.

In developing and carrying out the processes, various results are acquired that furnish the data needed to compute the metrics to be described in what follows.

An advantage of getting information in this way is that the data for metrics arise as a by-product of information needed to understand and design the system itself, taking advantage of the motivation to correct the system, rather than a more artificial, lesser objective of just getting metrics of complexity.

After the problematique is developed, a continuation of the process to develop options and sets of options forming a qualitative design leads to an alternative system design. Repeating this process can lead to several alternative designs, hence one can accumulate data for computing metrics of complexity for the alternative system designs in the manner to be described below.

Examples of such computations were published by Dr. Scott M. Staley[3] (Staley 1995) of the Ford Motor Company, where such computations were used to choose a particular information system design from three competing designs. The design with the minimum complexity metric was chosen.

5.3.6 Two types of metrics. The metrics to be discussed fall into two categories: situation metrics and problem metrics. All of the metrics are determined from group products emanating from the use of NGT and ISM.

5.3.7 Metrics for which data are found from the NGT products. Two significant metrics can be computed easily from the products of applying NGT. These are named the "Miller Index" and the "Spreadthink Index". The former is named after George A. Miller. Miller's work makes clear that the human mind can call into its working arena, its "scratch pad memory", only a few items (Warfield 1988). This being the case, why should anyone suppose that the many interactions involved in a system with more than a few variables could be dealt with by an individual manager or researcher without any frame for analysis that took Miller's findings into account? Miller's work, and follow-up publications by H. A. Simon and J. N. Warfield offer empirical and logical explanations for the asymmetric system learning trait.

5.3.8 The Miller Index (a situation index). The Miller Index is easily computed from the results obtained from NGT. Simply take the number of elements in the problem set and divide by 7. This gives a very conservative estimate of how remote is the possibility that, for many elements, all of the elements in the problem set could be considered simultaneously. At the same time if there are just 7 elements, then the value of the Miller Index would be 1. This gives a useful way to distinguish complexity from its counterpart. It also permits introduction

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[3] For a history of the long practice of Dr. Scott M. Staley in helping to develop systems science, please see Appendix 1 (Warfield, 2006).

of an alternate language to distinguish among the two components “oxygen” and “nitrogen”, namely the Domain of Normality (where oxygen resides) and the Domain of Complexity (where nitrogen resides), the two appearing to the distant (macro) observer to occupy the same cognitive space; while appearing to the micro-observer to be cognitively disjunct. A Miller Index value of 1 is the border value between the Domain of Complexity and the Domain of Normality; the latter being the Domain where virtually all work in higher education is carried out.

Forty-three values of this index computed in the 1980s (Warfield 1994) showed a minimum of 5.1, a maximum of 18.1, and an average of 9.2 These values are representative of what has been seen in intervening years. No value has ever been seen that is as low as 3, for example, hence in every instance the presence of complexity has been indicated. It can be reasonably inferred from this that people do not attempt to apply the systems science unless other methods have failed them, for otherwise it might be expected that now and then a value of less than 3 would have been seen.

5.3.9 The Spreadthink Index (a situation index). Spreadthink refers to the differences of viewpoint among individuals when voting on the five most important elements in the NGT selected subset. If each chose the same subset, the value of this index would also be 1. The value of this Index is found by counting the number of elements in the selected problems subset and dividing that number by 5. If everyone were in agreement on the most important elements, the value of the Spreadthink Index would be 1. Values of the Spreadthink Index coming from 43 instances of 1980's data are as follows: minimum value 3.8, maximum value 13.8, average value 6.8. These values should help understand why this index is so named.

5.3.10 Metrics for which data are found from the ISM products. The problematique enables the computation of three problem metrics and two situation metrics. The problem metrics will be discussed first, since an understanding of them will help to understand the situation metrics.

5.3.11 Problem metrics. For each problem shown on the problematique, it is possible to count the number of *antecedents* (i.e., the number of problems that aggravate that particular problem). This number can range from zero to (one less than the total number of problems shown on the problematique).

For each problem shown on the problematique, it is possible to count the number of *succedents* (i.e., the number of problems that are aggravated by that particular problem). This number can also range from (zero to one less than the total number of problems shown on the problematique).

The number of succedents for a given problem is called the *Influence Score* for that problem. The higher the *Influence Score*, the more that problem aggravates other problems. An initial hypothesis would be that the problems with high *Influence Scores* should be worked on first

The sum of the succedents and antecedents for a given problem is called the *Activity Score* for that problem. The higher the *Activity Score*, the more the given problem interacts with other problems. A problem may have a high *Activity Score* even with a modest *Influence Score.*

Subtract the *Antecedent Score* from the *Succedent Score*. If the result is positive, the particular problem tends to aggravate more than to be aggravated, but if the result is negative, the particular problem tends to be aggravated by others more than to aggravate others. This *Net Score* is helpful in interpreting the problematique, and in determining a strategy for future actions.

5.3.12 Situation metrics. Two situation metrics are computed from data taken directly from the problematique. These are the De Morgan Index and the Aristotle Index.

5.3.13 De Morgan Index (a situation metric). The reader who is familiar with the problematique (of which many examples have been published from many applications (Warfield 1990, 1994, 2002; Staley and Warfield 2007), should find this description straightforward. Others will benefit by studying any one of the relevant references. Let X and Y represent any two problems on the Problematique. If it is possible to get from X to Y by following the arrows, it is said that X and Y are "in the relationship" represented by the problematique (which is "significantly aggravates") and that there is a "path" from X to Y on the problematique. The *De Morgan* Index is found by counting all the unique paths on the problematique and dividing by 10. A value of 1 for this Index is the borderline between the Domain of Normality and the Domain of Complexity (Warfield, 2002).

The *De Morgan Index* was evaluated by Dr. Scott M. Staley of the Ford Motor Company following twelve Interactive Management Workshops held at Ford. The values ranged from 11 to 51, with an average value of 26.   For this set of workshops, the *Miller Index* ranged from 8.4 to 18.7, with an average value of 12.

5.3.14 Aristotle Index (a situation metric). This metric, discussed above, combines the syllogism of Aristotle with its one-sentence phrasing by Abelard, and the corresponding graphical construct showing an element, its antecedent, and its succedent as the three components of the reconstructed syllogism. The syllogism, discovered by Aristotle, is widely recognized among scholars as a fundamental breakthrough in comprehending formal human reasoning. In graphical terms, it corresponds to paths on a digraph of the form (X,Y), (Y,Z). Counting all such paths on the problematique one arrives at a count of the number of "graphical syllogisms" contained there. Dividing that count by 10 yields a number that is called the *Aristotle Index*. For a single syllogism, the Aristotle Index is 0.1.

The Aristotle Index measures the number of syllogisms in the problematique; and interpreting the number in this way helps explain why the problematique represents a very tight logic formulation that is seldom found to require any changes in the weeks and months following its development. Inevitably some changes could occur over time due to the introduction of new elements or to the removal of old elements as a result of successful implementation of a design.

It is commonplace to find several hundred syllogisms on a problematique. Can you believe that managers think they can intuit ways to resolve such situations without applying the kinds of processes that have been constructed to assist people in working with problematic situations that involve such attributes? Believe it!!

5.4 Products from applying the work program of complexity

Major products of applying the work program of complexity have been discussed, but the aggregate of the products has been omitted from the discussion, since the products have been discussed in detail in many of the references. Nonetheless, it is appropriate here to summarize them. **Table 4** summarizes the products from application of the WPOC, as determined by systems science. It is this composite array, mutually supportive, which accounts for the importance of preserving systems science intact, and not disturbing its components in the mistaken belief that it is comprised of independent parts, rather than a highly-integrated discursively-linked body of knowledge, with coupled theory and empirical evidence.

Table 4. Typical Products from application of the WPOC

Nature of product	Product	Notes
Tangible	P1 Set of key problems in the nitrogen situation	Identified in the NGT voting process
Tangible	P2 Problem field; i.e., problems arrayed in categories	ISM is used to create a "first draft"
Tangible	P3 Voting records on problem importance	NGT voting record reveals spreadthink
Tangible	P4 Named categories of problems	Categories are "dimensions of the situation"
Tangible	P5 Type 1 problematique	A structural graphic--problem interactions
Tangible	P6 Type 2 problematique	From the combination of P4 and P5
Tangible	P7 Complexity metrics	Computed from P1, P3 and P5
Tangible	P8 Options field, i.e. options arrayed in the dimensions	Anticipating applications of Ashby's Law, options are generated by matching to the problem dimensions
Tangible	P9 Optionatiques	How some options support others
Tangible	P10 Design alternatives	Combinations of options chosen from P8, at least one from each dimension
Tangible	P11 DELTA Chart	Shows work program design, activities, events, decisions, precedence
Tangible	P12 Work breakdown notebook	Amplifies the DELTA chart with work time, cost estimates, people
Tangible	P13 Observatorium concept	Estimates wall space, amendment times, learning spaces
Tangible	P14 Intermediate and final reports	
Intangible	I1 Substantial learning and insight into "nitrogen" situation	
Intangible	I2 Enhanced respondent organizational morale	
Intangible	I3 Process self-validation enroute	Data on spreadthink, data on problematique
Intangible	I4 Development of discursivity in "nitrogen" situation	NGT process reveals linguistic inadequacy, gradually removed
Intangible	I5 A management cadre for resolving the "nitrogen" situation	

6 Managing the Unmanageable

The application of systems science to resolve nitrogen situations has been described as "managing the unmanageable". This terminology is appropriate in the sense that the management practices typically taught in business schools are not founded in systems science and do not lend themselves to resolving complexity; at least not until the nitrogen situation has been resolved possibly into a collection of oxygen situations.

Wherever attempts are made to introduce complexity into such programs, a typical practice is to resort to metaphors or to various kinds of physical phenomena that are remote from hard-nosed practice.

To bring the nitrogen situations into the realm of the manageable, it is necessary to structure them. Structuring them involves structuring in terms of relative saliency (which ones are most significant in causing difficulties?), relative influence of components upon each other (how do they interact from a mutual causality perspective), and in terms of temporal activity (in what work sequences should they be attacked, and with what amount of work force for what period of time?). These are matters of detail that are not resolvable by individual managers, but rather require the aggregated and integrated perspectives of people working together. Moreover they require the assistance of a computing machine that is able to perform logic operations that reflect what the machine is told by people who understand interactions among components of the nitrogen situation.

6.1 The New Resource Strategy

Because there is so much vested interest in the old ways, and so much momentum in doing things the way they have always been done, and because much of what is being done should continue, the new resource strategy has been envisaged as probably the only realistic way to initiate and sustain a systems science program of the type that is required. This strategy presumes not only that the program will be financed by a source external to higher education, but that this source will take pains to assure that the funds, once released will not also release the obligation as to how the funds will be deployed. The provider of the funds must also provide the oversight to assure that the Horizons College can function in the manner described in this article, otherwise the gains potentially available may not be realized.

6.2 Interaction Budgeting

The Horizons College will be a new organization and a new concept in the envisioned university of the future. As such, it will necessarily encroach on the existing status quo, and perhaps be seen as a threat or competition for the existing attention and, more importantly, resources (students, faculty, facilities and money) of the university. Therefore the Horizons College must be budgeted as an “added-starter” receiving new funds for its creation, not being funded by reducing the budgets of other parts of the University.

In addition to the funding for the start-up and basic operation of the Horizons College, additional funding must be provided for the “interactions” of the Horizons College with the other parts of the university shown in Figure 3. Over time, nearly all these “interactions funds” could be expected to come from the Respondents. But initially, and realistically, start-up investment should be expected to be required for some period of time.

The Horizons College will necessarily be the sole controller of the interactions budget. As the continued reputation and sustainability of the Horizons College will depend on responsive performance in service to the Respondents, the Horizons College would operate as a profit and loss center of the university with the power to draw on the best qualified resources and talent from within and outside of the university to accomplish its mission.

Interaction Budgeting is based on the concept that you do not get what you do not budget for. Since interactions are fundamental to the success of systems science and the operations of the Horizons College, those interactions must be budgeted.

6.3 Project Followup and Reporting

Every science inherently benefits from continued learning. As Charles Sanders Peirce noted, to each science there must correspond a "community of scholars" who serve constantly to evaluate and amend the science. For systems science, the community that can be trusted must be the community that, first of all, understands the extant science, both in terms of its strength and its weakness. Only such a community can be trusted to engage adequately in helping respondents apply the science; for it is in the applications that weaknesses or essential changes can be detected, hypothesized, tested, and incorporated responsibly. And it is only in applications that its strengths can be honored and not dishonored through lack of understanding.

Systems science, as it stands today, benefitted considerably from its application over a period of more than a decade in Ford Motor Company, with continuity from Dr. Scott M. Staley. Several aspects of the science grew out of a long collaboration, observing what could be done to enhance the science (Staley and Warfield 2007). Several ideas that have yet to be implemented accrued from experience in that company. More ideas will arise as the number of applications grow.

Project followup must come from applications and from reporting. Whenever something is necessary, it must be reflected in budgets. Just as interactions with inside components of an organization have seldom been budgeted, consequently have almost never happened, so budgets with external components may never happen. A portion of the budget of the Horizons College should be reserved to pay for project feedback from respondents.

7 Summary

There is a very strong need in society for a systems science program of the type defined here. This program should be initiated and sustained in higher education, using a new resource strategy to connect a Horizons College to a hospitable existing university with a strong contract, fiercely enforced.

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