SELECTION AND SEQUENCING OF SYSTEMS CONCEPTS FOR SYSTEMS EDUCATION:
Case Studies in Integrated Science & Environmental Science

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Abstract and Keywords

This paper advocates the use of a small, select number of systems mechanisms to integrate and simplify the teaching of general education science and environmental science in college curricula. A "master" list of 80 systems mechanisms is reduced to 12 major processes. These are then placed in a presentation sequence based on level of difficulty, pedagogical purpose, and need for prerequisite knowledge. A distinction is made between what might be taught about each systems mechanism in courses dedicated to systems science curricula and the courses described here in which the systems mechanisms are used primarily as a delivery vehicle for specialty-based knowledge. A series of case studies are suggested for general education science for some of the 12 major processes.
Keywords: systems education, environmental science, science general education, isomorphies, curriculum development, case studies.

A New Strategy for Systems Education

The last decade has witnessed the demise of several outstanding systems education programs. For example, the formerly robust programs at University of Louisville, University of Denver, Stockholm University, University of Southern California (USC), University of Pennsylvania (Wharton), San Jose State University and others have closed. How can we begin a trend of increase and spread of the concepts of systems science to replace this recent trend of decrease? These events are all the more ironic considering that recent interest in the "sciences of complexity" (which are fundamentally systems science) has exploded.

One strategy for increasing recognition of the systems sciences would be to *use them to teach widely accepted and critically important subjects*. Two very basic subjects that must be taught everywhere today are *general education (GE) science* and *environmental science*. We propose using systems science to teach both general and environmental science more efficiently and effectively. We are doing more than propose; we have active curriculum design projects in progress to accomplish both [12,13]. These projects are supported by grants from the California State University System and the National Science Foundation. The purpose of this paper is to describe what portions of the unique knowledge base [8] of systems science might best be used to teach general and environmental science.

Because the processes of systems science are "transdisciplinary", they are sure to be found in many of the conventional subject areas of the natural sciences. Since they are "scale invariant", that is, they are found at virtually all scales of reality, they are often the "key" mechanisms, the most fundamental mechanisms in many fields. They would not be found in so many disciplines, or on so many scales that arose independently of each other and at different times since the Big Bang, if they were not required at all those levels and scales for natural systems to survive. Knowledge of them should be useful not only to understanding any particular natural system, but also to diagnosis of a malfunctioning natural system, and prescribing ways to improve the "health" of a natural system. We have demonstrated in other articles [10] that many sciences use systems concepts without recognizing them as such. Klir has recently pointed out that many systems processes are utilized in explaining biological phenomena and that this trend is likely to continue and increase [3].

The interdisciplinary nature of systems mechanisms would also help introduce students to the central problems and potential solutions characteristic of environmental science. Although some ecology texts have emphasized the importance of systems approaches [1,5,14], the majority do not make explicit use of or mention the systems sciences, and a host of recent environmental science texts (as distinct from ecology texts) only use systems concepts implicitly. Yet, this very popular course series involves applications of knowledge in virtually all disciplines. Because of this, students of environmental science are often lost in the details. There is a need in environmental science for summary, synthesis, and simplification especially for non-scientists who should take this course series because of its central importance to both state and citizens practical decision-making. In fact, many more non-science students are taking environmental courses on college campuses today; interest has multiplied in the 90's. There is also a critical need for better bridges between the natural sciences of the environment, and the socio-economic and political sciences of the environment. Perhaps the "invariant" processes of the systems sciences could provide much needed integrative themes as well as the needed bridges between the natural and social sciences.

There are other areas of college studies that might usefully incorporate systems studies, further extending the strategy of incorporating systems education in conventional education. The Association for Integrative Studies (AIS), a professional organization about the same size as the ISSS which also focuses on synthesis and integration, has published a directory of interdisciplinary courses and curricula (which do not overlap with ours) that lists 237 programs nationally and internationally [4]. Their last newsletter (Vol. 15, No. 2) was devoted to two items; one a memorial obituary for Ken Boulding, one of our Founders, and the other the same systems science-based general education science program described here and in previous ISSS Proceedings [11]. So there already are some linkages between Integrative Studies and the systems sciences. Perhaps systems concepts could also be used in the many courses they list, although that is not the focus of this paper.

Here, then, are three conventional university curricula which are powerful and pervasive, each with associated K-12 components, that could act as "carriers" for systems science, while themselves benefiting from the infiltration and synthesis. For this strategy to succeed, or even for it to begin, the following questions must be answered: (i) what in systems science should be taught to the general student; (ii) at what depth should it be taught; and (iii) how can the general knowledge be best tied to the specific knowledge to the benefit of both?

Assemble A Comprehensive Master List of Systems Mechanisms

There are too many systems concepts; only a few of the most crucial and best demonstrated can be used if we are to accomplish the task of integrating other material and not overload the student. Simplification is the key. Our primary task is to teach another subject matter, not systems science *per se*. To guarantee that we do not leave out any important systems mechanism, we must assemble the most comprehensive list of systems mechanisms extant, and only then pare down the list to essentials.

A very essential characteristic of the systems concepts selected must be that each represent a pervasive "mechanism" or "process", not a mere systems term. We want to be able to define, describe, diagnose and prescribe characteristics of systems. Unless the integrative themes are fundamental to the structure and behavior of the natural and environmental sciences, they will not help us accomplish these four goals. Systems "live" and "stabilize" in the universe because of their structures and functions. The two sciences to which we would apply systems mechanisms are themselves preoccupied by "mechanisms" and "processes."

For an appropriate one-to-many mapping or general to specific integration, we must also concentrate on mechanisms.

The last two decades have produced various compendia of systems terms and concepts. I have reviewed them before [9], and new initiatives continue to appear [2]. They all differ because each has a different purpose and criteria for inclusion and exclusion. Table One is an alphabetical list of our current master list of significant systems processes and mechanisms. Each is thought to be scale-invariant, transdisciplinary, and essential to the origin, stability, maintenance, and continuance of a healthy system. They are sometimes called "isomorphies" because they have the same process "steps" or "form" at some abstracted level even though the manifestations of the "steps" or "form" is different in each case. We use the "noun" designation "isomorphy" rather than the adverb or adjective "isomorphic" used by GST founders which denoted only comparison because we believe that these patterns are functionally generic. Their minimalism precedes in time and directs the emergence of particular systems. This conceptualization is a radical departure from our usual view of the universe; however, it is not necessary to embrace or even agree with this idea to employ systems isomorphies to improve other educational programs. What items should we select from this list to teach general education and environmental science?

Criteria For Selection

To serve adequately as "Integrative Themes" chosen systems concepts must: (i) be mechanisms or processes with important functions in natural systems, (ii) be found in all of the seven sciences covered in the course (that is be transdisciplinary), (iii) be understood in sufficient detail that "deep" information about the systems mechanism is available, (iv) be potentially integrative, that is, the identifying characteristics of the systems mechanism are clearly seen in a diverse enough set of examples to support the argument that the special cases are all variants of a more general, single case, (v) be capable of supporting detailed case-studies that non-trivially illustrate the important phenomena of each of the seven conventional science disciplines represented, (vi) be rich in potential graphic, audio, and animation presentations and demonstrations, (vii) be useful in promoting understanding of the impacts of science on society, (viii) be useful in improving our understanding of social systems, thereby integrating both natural and social systems, (ix) be representative of an interesting advance in human knowing, and finally (x) be intrinsically capable of helping students understand natural systems at a deep level.

Table One: Alphabetical List of Isomorphic Systems Mechanisms or Processes

1. Allometry Patterns
2. Anergic Mechanisms
3. Ashby's Conjecture (Requisite)
4. Attractors (Point, Periodic, Mixed)
5. Autopoiesis, Allopoiesis
6. Bifurcations
7. Boundary Conditions
8. Catastrophe Processes
9. Closed Systems
10. Competitive Processes
11. Cooperative Processes
12. Counterparity Mechanisms
13. Coupled Feedback Processes
14. Couplings
15. Cycles and Cycling
16. Decay Processes
17. Deutsch's & Dollo's Conjecture
18. Development Patterns & Laws
19. Dissipative Structures & Processes
20. Duality Mechanisms
21. Emergence Processes
22. Energy Flow Processes
23. Entropy
24. Equilibrium Processes
25. Ergodic Processes
26. Evolutionary Processes
27. Exclusion Principle
28. Feedback Processes
29. Feedforward Processes
30. Fiegenbaums Constant
31. Field Dynamics
32. Fractal Structure, Time, & Processes
33. Fragmentation Processes
34. Flows, Generic Rules
35. Growth Patterns & Laws
36. Hierarchical Structure & Process
37. Homeostatic Processes
38. Hypercycles
39. Input Mechanisms
40. Information Flow Processes
41. Integration Processes
42. Instability Mechanisms
43. Least Action/Energy Principles
44. Lifestage Cycles
45. Limit Cycle Processes
46. Limits, Physical
47. Limits, Informational
48. Lotka-Volterra Substitutions
49. Lyapunov Functions
50. Maximality Principles
51. Meta-Heterarchical Str & Processes
52. Minimization Principles
53. Morphodynamic Processes
54. Negative Entropy
55. Negative Feedback Mechanisms
56. Network Dynamics
57. Non-Equilibrium Thermodynamics
58. Open Systems
59. Oscillations
60. Output Processes
61. Periodic Processes
62. Phases
63. Plenitude, Principle of
64. Positive Feedback Mechanisms
65. Potential Spaces or Fields
66. Power Spectrum of Physics
67. Replication-Recursive Mechanisms
68. Restructuring Rules
69. Self-Organizing Processes
70. Singularities
71. Soliton Theory (Long Waves)
72. Spin Processes
73. Stability Processes
74. States
75. Steady State Mechanisms
76. Strings, Generic Systems
77. Symmetry, Systems-Level
78. System Identification, Sub-, Super-
79. Taxonomy, Systems
80. Transgressive Equilibrium
81. Variation Mechanisms
82. Zipf's/Pareto's Conjecture

Another criterium, so significant that it stands alone, might be that the natural sciences already have developed a sensitivity to the selected systems integrative theme *within their own knowledge domain.* As we are serving the faculty of the natural sciences, it is important that they not find our major themes too "strange" or unrelated at all to the phenomena of their discipline.

Criteria for Sequencing

Sequencing of the systems processes used as integrative themes is also essential. Some systems processes require prerequisite knowledge. This knowledge must be presented to the non-science students who are the target audience of these courses before presenting the systems process. Some systems mechanisms are derived from or dependent on other systems processes. They must be presented in the order demanded by this interdependency. Some are intuitively easier to understand. These should be presented first. Some are part of popular lore and have corresponding representatives in well known human systems. This popular pre-knowledge of the mechanisms has both positive and negative consequences. It is positive because students already have an introduction to and are familiar with the process. But it also has significant negative impacts because much of this pre-knowledge may be wrong and require both unlearning and relearning, which are particularly difficult tasks for any human. For example, hierarchical structure or clustering is a very common structure. But seeing it as the result of a process is less common. Also, popular concepts of hierarchy in the social sciences are diametrically opposed to findings about hierarchies in natural systems. So as much unlearning has to be accomplished about this concept as new learning. Some systems processes come earlier in the Piagetian scheme of conceptual abstraction than others. More difficult systems processes can be learned only at certain stages of intellectual development, and not at all, or only with great difficulty at earlier stages. The order in which the systems mechanisms are presented must reflect all of these concerns.

There also must be an "internal logic" or at least appealing "storyline" to the chosen sequence of systems mechanisms. This rationalization of the sequence of the integrative systems themes should be communicated clearly to each entering student, and the sense in the sequence should be recommunicated regularly throughout the course series. Understanding of the numerous specific case studies covered during the three quarters would be much enhanced by constant awareness of the "gradual build-up" across the sequence of systems mechanisms used as integrative themes.

Clustering Reduces Numbers, Increases Coverage and Meaning

One strategy for maintaining some of the detail of the longer list of processes listed in Table One while reducing the number of "integrative themes" which the student must learn might be to make superclusters of the processes. Three ways that we have used in the past to compact the long list of putative systems mechanisms are shown in Tables 2,3, and 4. Table Two reorganizes the list of 80+ mechanisms in "similarity-of-function" clusters in the form of a common outline structure. For example, negative feedback, positive feedback, coupled feedback, feedforward, 2nd and 3rd order feedbacks, etc. are gathered into a cluster of processes that serve as "regulatory mechanisms" which result in short-term maintenance or longevity of the system. Table Three shows only a small part of an "interaction matrix" of the systems mechanisms. Each bubble or node is a different systems mechanism and each line is a directional or mutual influence of the two thus interconnected mechanisms. You may notice that this clusters the mechanisms into naturally interacting sets. Elsewhere we describe the vectors as "linkage propositions" [7]. This analysis naturally groups them into clusters based on the number and frequency of interactions between nodes. Table Four shows the mechanisms clustered by "stages" in the generic systems life cycle. Each of the big bubbles is a stage of the life cycle, and each of the small bubbles is one of the 80 systems mechanisms that serve as partial causes of that stage. This is our chosen organization of the many systems mechanisms for our dedicated systems courses because it reflects the actual functionality of each mechanism. But it has too much detail for the non-science, non-systems science student in our opinion.

We have essentially chosen a modification of Table Two as the simplest way to reduce the number of systems mechanisms for the non-science student audience. The other two would require much more indirect explanation before they could be used as integrative themes. Although they have pedagogical value on their own, it is at a higher level of understanding and detail and is better left to students studying systems science directly.

Working "Selection" of Systems Processes or Integrative Themes

In the Integrated Science General Education curriculum under development at our Institute, we plan to use only 12 *clusters* of systems mechanisms as integrative themes. Our planned 30 week course series reserves 6 weeks for coverage of the scientific method which is a major integrative theme in itself. This leaves 24 weeks for integrated coverage of

Table Two: Clusters of Systems Mechanisms for Simplification

1. Systems Definition
1. System Identification, Sub-, Super-
2. Boundary Conditions
3. Closed Systems
4. Open Systems
5. Taxonomy, Systems

2. Systems Structure
1. Development Patterns & Laws
2. Hierarchical Structure & Process
3. States
4. Phases
5. Duality Mechanisms
6. Negative Entropy
7. Symmetry/Asymmetry, Systems-Level
8. Fractal Structure, Time, & Processes
9. Strings, Generic Systems

3. Systems Linkages
1. Generic Flow Rules
2. Couplings, Types of
3. Input Mechanisms
4. Output Processes
5. Energy Flow Processes
6. Information Flow Processes
7. Anergic Mechanisms
8. Synergistic Processes
9. Dissipative Structures & Processes
10. Cooperative Processes
11. Competitive Processes
12. Network Dynamics
13. Transduction Mechanisms

4. Systems Maintenance (Short Term)
1. Stability Processes
2. Steady State Mechanisms
3. Feedback Processes
4. Negative Feedback Mechanisms
5. Coupled Feedback Processes
6. Equilibrium Processes
7. Homeostatic Processes
8. Feedforward Processes
9. Hypercycles
10. Non-Equilibrium Thermodynamics
11. Ashby's Conjecture (Requisite Variety)

5. Systems Behaviors
1. Equifinality & Mechanisms
2. Instability Mechanisms
3. Cycles and Cycling
4. Oscillations
5. Attractors (Point, Periodic, Mixed)
6. Limit Cycles
7. Bifurcations and Catastrophe's
8. Ergodic Processes
9. Lyapunov Functions
10. Periodic Processes
11. Soliton Theory (Long Waves)
12. Singularities
13. Spin Processes

6. Systems Transformations (Long-Term)
1. Positive Feedback Mechanisms
2. Variation Mechanisms
3. Restructuring Rules
4. Decay Processes
5. Catastrophe Processes
6. Second and Third-Order Cybernetics
7. Complexification Mechanisms
8. Lotka-Volterra Substitution Patterns
9. Transgressive Equilibrium
10. Evolutionary Processes

7. Systems Environment
1. Entropy
2. Exclusion Principle
3. Least Action/Least Energy Principles
4. Limits, Physical
5. Limits, Informational
6. Maximality Principles
7. Minimization Principles
8. Potential Spaces
9. Plenitude, Principle of
10. Field Dynamics
11. Power Spectrum of Physics

8. Systems Patterns or Trends
1. Allometry Patterns
2. Fragmentation Processes
3. Growth Patterns & Laws
4. Morphodynamic Processes
5. Lifestage Cycles
6. Zipf's/Pareto's Conjecture
7. Meta-Heterarchical Structure & Processes

9. Systems Origins
1. Counterparity Mechanisms
2. Autopoiesis, Allopoiesis
3. Integration Processes
4. Self-Organizing Processes
5. Emergence Processes
6. Deutsch's Conjecture; Dollo's Law

COMPOSITE OF SELECTED LINKAGE PROPOSITIONS
FOR SEVEN ISOMORPHS

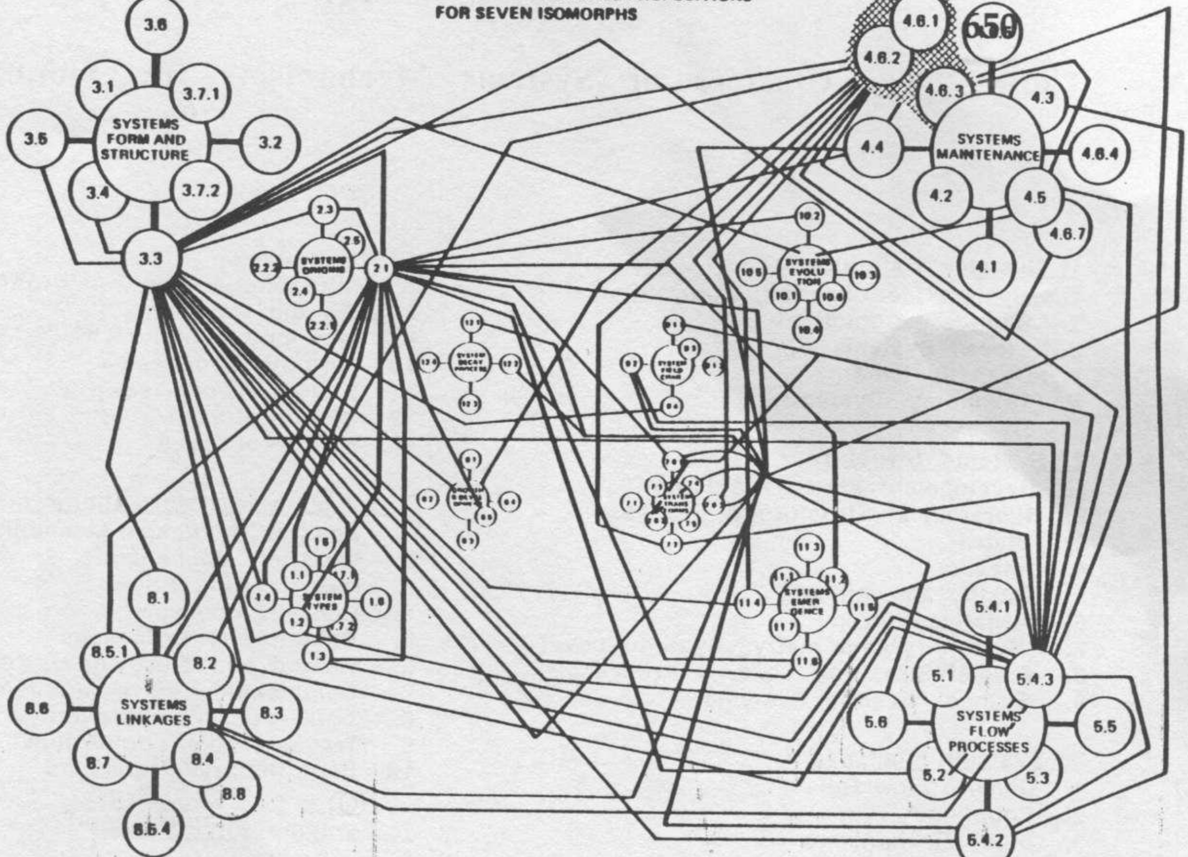

TABLE THREE ABOVE

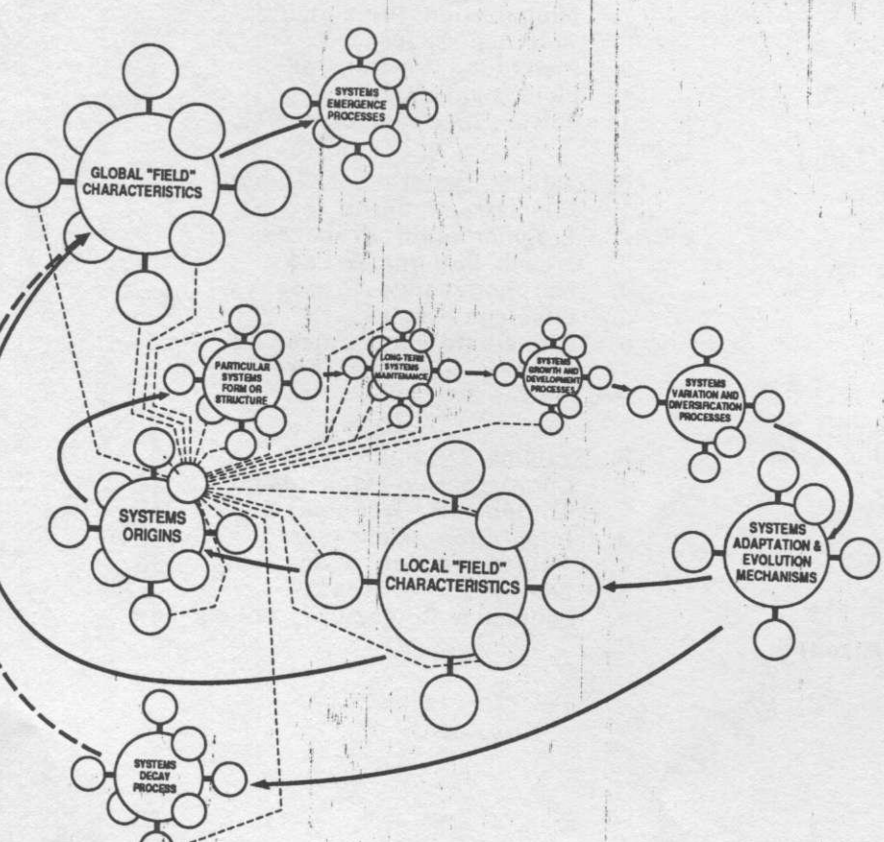

TABLE FOUR LEFT

the phenomena of the seven sciences. We have elected to present one new theme every two weeks. Thus, we are restricting ourselves to only a dozen systems mechanisms as integrative themes. Our working list of integrative systems themes is as follows:

(1) Scales of Nature (Hierarchical Clustering)
(2) Systems ID, Organization, Function, and Taxonomy
(3) System Flows: Physical, Energy, & Information
(4) Networks and Fields in Systems
(5) Regulatory Feedback Mechanisms
(6) Equilibrium and Stability Mechanisms
(7) Cycles and Oscillations
(8) Limits, Growth & Development Patterns in Systems
(9) Dualities and Symmetries in Systems
(10) Integration and Fragmentation Mechanisms in Systems
(11) Chaotic Dynamics in Systems
(12) System Origins and Evolution

It is interesting to note that although the list of 80+ isomorphies in Table One as well as the above list essentially come from 20 years of accumulation of study at our Institute, they *encompass all* of the "Common Themes" recommended for science education in Chapter 11 of the landmark AAAS study *Project 2061* [6].

<u>Working "Sequence" of Systems Processes or Integrative Themes</u>

The above list is displayed *in the order and sequence of presentation.* The following notes on relative placement of each systems mechanism are not yet complete and we welcome your input and insight. The first set of four integrative themes taught the first quarter emphasize basic systems structure and the flows and fields that maintain and enable that structure. This set has the immediacy of describing the parts of natural systems in still images, frozen in time. The set of four taught the second quarter emphasize the dynamic flows which develop the systems form described during the last quarter and enable it to manifest short-term responses to preserve its identity through time. The third quarter will focus on mechanisms that give natural systems relatively long-term adaptive responses resulting in the appearance of new systems from old or the merger of systems. Notice that progressively longer and longer spans of temporal awareness, and awareness of more and more dynamic behaviors are required of the students as they progress through the 12 themes. Together they touch upon many of the 80+ isomorphies listed in Table One.

Hierarchies: We have placed "hierarchical clustering" first simply because it will give us an opportunity at the beginning of the course to introduce the student to a panorama of all the "entities" recognized in nature. Hierarchies and scales give a vast overview and yet simplification of the many diverse entites of natural systems. One of the criticisms of conventional GE science curricula is that students leave their personal and idiosyncratic choice of a smorgasbord of courses without a clear understanding of many of the entities in nature, their characteristics, names, and relations. Massive "blind spots" and "misunderstandings" result. With this beginning we can help eliminate this fault of conventional GE science education. Hierarchies will also allow us to demonstrate that the seven science specialties themselves have resulted from a gradual historical evolution of human awareness of the different scales of nature. It will also allow us to introduce the importance of the discovery of new principles and the invention of new scientific instruments in extending human senses so that new "entities" could be included in our understanding of natural systems. Actually concepts of hierarchy, like those used to make common english outlines, are not the easiest to grasp or the first that children become aware of during normal Piagetian concept development. However, we feel the above functional reasons outweigh any consideration of inherent difficulty especially for college-level students.

Systems Structure: The second theme would be systems identification which would include the concepts of systems boundaries, subsystem, supersystem, the concept of the environment surrounding the system, and generic systems structure. This develops some detail for each of the entities presented in the progression of entities introduced by the last theme. Although the entities differ drastically in scale, they still share some overall structure in common. At this point, however, there is not much awareness of the dynamics of that structure since it is easier for students to understand static form before adding dynamics to it.

Systems Flows: The third theme would establish that most surviving systems are open systems that require inputs and outputs of materials, energy, and information between the environment and themselves. The rules and patterns of these inputs and outputs as well as the conservation rules of the physical world could be presented as maintenance mechanisms for systems. Flows would be presented as manifesting the entitation of the system. Again, although the systems presented in the first theme are vastly different from each other in terms of their parts, still those parts experience flows that have essentially the same function when the different systems are compared.

Networks and Fields: The fourth theme would emphasize that the many flows that support a system result in multiple connections between systems within any level and across many levels of reality; and these flows we characterize as a network. The general rules that govern networks and the "fields" they exist in would be a natural follow-up and a climactic ending for the first quarter, because we can show how interaction frequencies and scales of networks relate back to the concept of specialty sciences and hierarchies.

Feedbacks: We would start the second quarter with the various aspects of feedback that enable a system to adjust itself to the requirements of its immediate environment. These and the next three themes would be presented as special cases of flows which render the system stable in time and so identifiable by man. An understanding of flows and systems in general is necessary before the student can add these more complex versions of flow in 2nd quarter themes.

Stability and Equilibrium: Usually stability and dynamic equilibrium can be achieved only through feedback, so this theme would immediately follow that. Now we could introduce the idea that systems form is not a static form, but instead a short-term and long-term dynamic form that can be achieved by all the themes presented so far.

Cycles and Oscillations: Coupled feedbacks are also needed to describe the mechanisms that cause and maintain cycles and oscillations.

Limits and Growth Patterns: Once a system has maintained a reliable structure and short-term set of adaptations to a changing environment, it must conform to a set of universal limits to its structure and behavior not only during its growth but its development. This theme marks the culmination of the second quarters work

Symmetries: An understanding of dualities, their generative capacity, and their role not only in systems form but in systems origin begins the third quarter of presentation. We defer these processes until now because we wish to emphasize the role that dualities play in systems origins and evolution, which is the overall theme for the third quarter. Humankind often perceives and understands structures before it understands the dynamics of the structure, and then finds it easier to understand immediate-time dynamics than to understand long-term dynamics or origins from disorder. So we reserve the questions of origin and evolution until the last quarter.

Integration and Fragmentation: Over the long-term most systems exist in very large populations of their type. Each of these systems differs from the other in enough ways to add to the diversity of the population, but are sufficiently similar to maintain membership in the population. Because of the large numbers there is a tendency for "fragmentation" into smaller sets that vary from each other. Over time these variants establish new complex relationships with each other that result in new levels of complexity of units that repeat the process. The sciences themselves will be shown to be just one of many natural systems that oscillate between the two mechanisms.

Chaotic Dynamics: In the modern sciences of complexity, chaos is seen at the origin of any systematic pattern, and then marks the dynamics of behavior of the system thereafter. However, it requires the most mature and prepared mind to perceive potential order in chaos, gradual emergence of order from chaos, and the non-linear behavior of many systems. So we save it for next to last.

Systems Origins, Evolution, Emergence: The final theme of the final quarter introduces the mechanisms that require the longest temporal span and participation of virtually all of the mechanisms presented to date.

How Much Detail to Present for Each Systems Process

The capacity of the non-science student for detail is legendary. A balance between the depth of coverage presented in systems courses or major-based science courses and the depth of coverage normal for the target audience is necessary. We want to attract the non-science student to the subject material of the natural and environmental sciences using the systems mechanisms, not overload and alienate them. It is also usually in the interest of synthesis and integration to simplify. The list below shows the 20 categories and levels of detail we attempt to cover for each of the 80 systems mechanisms in Table One during our 14 course series for an Institute Minor in Comparative Systems Analysis. They are described elsewhere. Only the categories marked by an asterisk rather than a bullet would be covered in the Integrated Science Program suggested here (and then only for the 12 major systems processes listed above):

...For Each Systems Process...

** *Identifying Characteristics or Criteria (Qualitative, Descriptive)*
• Comparative Definitions
** *Intriguing Examples in Real Systems (Exemplar vs Case Study)*

- Role or Function in Systems Life Cycle
- Discinyms
- Linkage Propositions on...
- Types and Taxonomies
- Formal Development (Computer Representation & Simulation)
- Formal Development (Mathematical)
- Tests For Transdisciplinarity
- Analysis of Requirements and Pre-requisites
- Special Techniques
- Relationship to Systems Analytical Methods
- Role in Known Pathologies of Systems
- Design Intervention Opportunities (DIO's)

** *Discovery and History*

- Data to Date
- Graphics, Sound, Animation, and Slide Inventory
- Evaluation of Current Status: Future Questions
- Literature Data Base
- Institutions and Workers

Match Systems Themes with Case Studies in Integrated Science

One tried and true methodology for introducing students to a vast knowledge base is to describe discrete principles that are fundamental to that knowledge base, and then to follow with a specific case study that illustrates the principle in considerable detail. In this way the needed overview is accomplished (with the principles) and students get a taste of the tremendous detail in the field (using the case studies). The student can then extrapolate to all the other potential case studies which they do not have time to study. The combination gives students a sense of the breadth as well as the depth of the field that normally comes only from a lifetime of study and experience. In the curricula described here case studies have an additional service to perform. By judicious choice of at least one detailed case study from each of the sciences (astronomy, physics, chemistry, biology, geology, mathematics, computer science) students may be intrigued to see that key phenomena in all of these differing scales of reality *share the same dynamics*. These case studies deliver perception of integration and synthesis as well as detail.

There already is a considerable interest in systems processes in the natural sciences. However, the processes are virtually always described in reductionist, strictly disciplinarian terms and their cross-disciplinary features omitted. In fact, they are not developed at all as "principles" of that science. Principles of the discipline are usually restricted to processes *only found within that discipline*. Still, as time goes on, and many specific processes are elaborated (eg. in cell biology, or ecology) some workers even within conventional disciplines are beginning to point out how aspects of the process they are studying is similar to aspects of other processes already studied.

Consider cell and molecular biology. The detail now discovered and verified in these fields is such that "basic" texts run for 1200 pages and many hundreds of different proteins, nucleic acid sequences, organelles, and discrete processes and interactions are described. Numerous and very specific "feedbacks" have been proven between these cell and molecular entities. Still one rarely finds "feedback" discussed generically in the text. It is only presented in each specific case it is found and only in terms of the specific reductionist entities involved. Never is the concept of feedback mentioned as a mechanism found in many other disciplines and what is common between them. In a recent study of the concept of "hierarchy" it was found that over the 7-year period from 1985 to 1991 journal article abstracts covered in the data bases BIOSIS and MEDLINE included the term in averages of 381 and 246 articles per year respectively. Yet this concept is not discussed in most texts explicitly at all, and never as a cross-disciplinary mechanism or structure. So the basis for using mechanisms like "feedback" and "hierarchy" exist in biology and medicine, but are not developed there. In another paper we will list several specific cases of use or demonstration of each of the 80+ systems mechanisms for each of the seven sciences

Our conclusion is that there exists many highly-developed, reductionist examples of all of the systems mechanisms in each science that could serve as excellent case studies, but that they do not receive much explicit attention in their home literatures. Table Five summarizes in highly compact form some examples of case studies we might use for several of the key systems mechanisms proposed in our sequence.

Match Systems Themes with Cases From Environmental Science

There traditionally has been a considerable interest in systems processes in the environmental sciences. Since they are intrinsically an interdisciplinary science, there is a concomitant increase in awareness of systems processes *per se*. Texts such as those of Watt, Odum, and Allen specifically cite and use the knowledge base of systems science in developing ecological and environmental concepts [1,5,14]. These texts, however, are not the consensus texts. Still, it will be easier to use the systems-based integrative themes in this curricular development than that of the natural sciences. Our Institute has developed detailed teaching outlines for our courses in this area (CSA 201, 202, and 470).

Potential Benefits To Systems Science Of This Strategy

There are tangible, practical, and likely benefits to using this strategy. They include: (i) large increases in students taking systems-based courses; (ii) increase in exposure, acceptance, and publicity of systems science in conventional educational institutions; (iii) increase in student demand for our own systems science education programs (improved flow-through); (iv) direct challenges to systems workers to illustrate systems mechanisms at work in the natural sciences; (v) direct challenges to both natural and social systems workers to demonstrate systems mechanisms at work in the environmental sciences; (vi) attraction of natural scientists to the field of systems science and societies like ours; (vii) demonstration of the practical utility of the systems sciences; (viii) experience of the theoretical excitement and beauty of the systems sciences; (ix) increase in rigor of the systems sciences; and (x) a paradigm shift that puts systems science more at the center rather than the periphery of the curriculum.

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