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**On the Nature of Systems Thinking and Systems Science: Similarities, Differences, Potential Synergies**

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***Abstract***

***This paper clearly discriminates between the too-often-conflated terms, systems thinking & system science. It argues for a halt to this conflation. It presents a more comprehensive list than usual of different systems sources that must be unified to enable SE’s to learn & use systems science to increase use of its vast unused literature in SE. It presents a linear spectrum rather than opposition approach with thinking, philosophy and design near one end & several new systems-integrated sciences (including systems science) at the other. It suggests several differences & similarities between thinking & science so similarities could enable synergy & complementary improvement within & between the two mega-domains. Balancing the current emphasis on human-based systems thinking with increased study & use of the new systems science would result in a more rigorous, prescriptive, & evidence-based SE of greatly increased application range.***

***Keywords: systems thinking; systems science; isomorphic systems processes; systems process engineering; systems processes theory; systems mega-domains.***

**1. Statement of the problem: need to address directly**

Systems thinking is a phrase often used in the systems engineering field. A whole range of SE meetings (IW, IS, CSER, Chapters) use the term “systems thinking” exclusively to represent SE interests in the systems approach often using the phrase equally and interchangeably with systems science. The work and workers cited for this systems thinking are clearly useful for some aspects of SE praxis. But the available knowledge important to near-future SE praxis is much broader than that implied by the term systems thinking. SE must recognize that there are projects, problems, funding, and a vast,untouched, literature that represents an emerging science of systems. It would foretell and enable a much broader view of SE that includes husbanding and repair of a wide range of natural systems, human systems, and complex combinations or hybrids of natural and human systems. This expanded SE scope will require a deeper view of how systems work and don’t work (a much deeper systems theory) than simply project management. It will require a developed “science” of systems. But until systems engineers and systems scientists unify the currently very fragmented source information, there will not be a “systems science” despite the loose use of such a term by many workers. Two ongoing projects of the INCOSE-SSWG (Systems Science Working Group) are trying to develop a framework to help synthesize, unify, or integrate the very fragmented areas of systems approach.One purpose of this paper is to directly counter the conflation of the terms systems thinking & systems science. They are not and never will be the same.

* 1. Background of the problem: a long tradition of separation

Any conflation between the terms “systems thinking” and “systems science” is partly a result of already separated disciplines, the oft-cited “stovepipe” metaphor. Not only are disciplines made by beginning with distinct goals, often studying different scales of reality along the otherwise unbroken sequence of origins but they use different tools, methods, and have different guarantors of truth. To a group of systems-interested advocates such as this audience, we do not need to emphasize that the recent trend is to decry and bemoan the separation of fields at a time when we need whole systems solutions to crisis problems. When we began our professional career in 1970, interdisciplinary was a scorned word. Now it is a necessity.

But even today, when even transdisciplinary is desired, remnants of the “science wars” continue [1,2]. In the nineties, there was a public outbreak of articles in major journals representing both sides. Post modernists stated logical positivism and reductionism were dead and did not produce factual knowledge, but rather knowledge was socially constructed and so inherently subjective and human-based. Scientists stated that the post modernists had rejected objectivity as a possibility, objective methods in science, realism, and therefore much of the scientific knowledge base even though they were using its technological products daily. Scientists considered such fields as cultural anthropology, literature, history & philosophy of science as hotbeds of anti-science rhetoric and teaching. They argued that most of these critics of science had a very poor knowledge of science to begin with. This was not simply separate foundational disciplines keeping knowledge separated, it was aggression against scientific knowledge and values. Nothing could be more inhibitory to the emergence of a science of systems than this. In my talks and numerous invited webinars to INCOSE engineers [3], I have encountered representatives of both of these camps.

* 1. Negative effects of this tradition

One could elect to view this traditional separation, antagonism and mutual interference with understanding of the natural human need to preserve one’s own culture due to fear of threat or to preserve past investment. However, there are several real and harmful outcomes to this human tendency, namely: (i) it places a great burden on the communications and cross-comparisons that are the ultimate source of desirable cross-fertilization; (ii) it inhibits needed attempts at unification, synthesis, and integration; (iii) it constrains indispensable awareness of the other areas and their significance; (iv) it halts utilization of others knowledge bases; (v) it precludes teaching and learning across the areas by both the previous generation of professionals and the upcoming new generation of students; (vi) it widens the chasm developing between the approaches; (vii) it lessens an appreciation of the value of approaches different from one’s own.

* 1. Need for a unified systems knowledge base (KB) and an expanded view of SE

How can the new systems approach avoid the pitfalls of their foundational specialties that are just now becoming aware of the need for systems awareness yet simultaneously resisting each other? What would bring them together? Ironically this dilemma is not that different from the one facing our international spectrum of national priorities or our political spectrum in the U.S. today. It is the goal of two of the several official projects of the INCOSE-SSWG, one on Systems Processes Theory, and a second on Systems Pathologies (hereafter SPT/SP)to discover strategies to overcome these barriers. First, we will attempt to provide a common terminology/ontology of such utility that it attracts proponents to replace opponents [11-15]. Second, we will use a framework of how systems work (systems processes theory) and how they don’t work (systems pathologies)[18] to produce an integrated KB of such detail it becomes a valued and widely taught and used tool in the SE toolbox. Third, we will produce an image of systems engineering that opens jobs and funding to SE for a much wider set of applications. Imagine an SE that effectively became the place to go to design not just aerospace or manufacturing products but to curate and repair a wide range of human/natural systems complexes on all scales. Fourth, that KB will be presented in products that could be easily used and adapted for educating a new generation of SEs. But can any of this be accomplished if there is hostility between human-based systems thinking and natural science based systems science?

**2. Viewing systems mega-domains as on a SPECTRUM**

At a Sunday pre-conference workshop for the ISSS (International Society for the Systems Sciences), attended by a self-organized group of mixed systems engineers and systems thinkers, the 27 participants were given the challenge of listing all of the main workers in any systems area whose work they think should be integrated to form a KB for systems science. In 30-min, they produced a list of 56 (non-bold,Table 1).

The author of this report was moderator of the Workshop so did not submit his own candidate names. His additions for this paper (40 workers, shown in bold) represents only a partial list of those he considers important. Adding them together (Table 1) gives an initial list of nearly a hundred lifeworks that need to be synthesized. This task is one of the official projects of an ongoing SIG (Special Integration Group) of the ISSS and of the aforementioned INCOSE SSWG whose work is now connected by a memo of understanding between the two professional organizations. There are about an equal number of ST Lifeworks representing systems thinking to SS Lifeworks representing systems science, and a small number of the new Systems Integrated Sciences (SiS). These designations are the author’s opinion based on the criteria listed in section 4 and would probably be challenged by a number of the authors. But that is precisely the point of this paper. Many are claiming their work to be systems science when it is not according to our criteria. It is clear why they do this (wanting to capture the reputation of the sciences; or the major funding of the sciences; wanting to render their work more rigorous; wanting to justify greater efficacy of their work, etc.). So these should be considered just an initial designation to be debated much in the future. Works strongly math-based were counted as SS, works strongly management based or human system only based were counted as ST.

***Table 1:*** *Lifeworks in Systems to be integrated: Output of ISSS’13 Workshop, July x, San Jose, Ca. plus authors personal additions shown in bold. ST = Systems Thinking; SS = Systems Science; SiS = Systems-Integrated Sciences which are rather more SS*

1. **Abraham, R. (chaos math) [SS]**
2. Ackoff, R. (sys management) [ST]
3. **Allen, T. (hierarchies) [SS]**
4. Ashby, R. (sys management) [ST]
5. **Auyung, S. (complex systems) [SiS]**
6. Axelrod, R.M. (cooperation) [ST]
7. Bahm, A. (sys philosophy) [ST]
8. Banathy, B. (systems education) [ST]
9. **Bak, Per (self-criticality) [SS]**
10. Bar Yam, Y. (NECSI projects) **[SS]**
11. Barabasi, A.L. (network theory)[SS]
12. **Barrow, J. D. (physics) [SiS]**
13. Bateson, G. (sys philosophy) [ST]
14. Beer, Stafford (sys management) [ST]
15. Bertalanffy, Ludwig von (GST) **[SS]**
16. **Bogdanov, A. (organiz’l GST) [ST]**
17. **Bosch, Ockie (bayesian apps)** [ST]
18. Boulding, K. (GST & econ) [SS]
19. Bunge, Mario (sys philosophy) [ST]
20. Cabrera, D. (systems dynamics) [ST]
21. Callon, (actor net theory) [ST]
22. Capra, F. (chronicler) [ST]
23. Caws, Peter (sys philosophy) [ST]
24. Checkland’s, P. (soft systems) [ST]
25. Chomsky, N. (sys linguistics) [ST]
26. Churchman’s, C. (sys mgmnt) [ST]
27. **Corning, Peter (synergy, bio) [SS]**
28. **Cowan’s, G. (SFI) [SS]**
29. Doxiadis (ekistics) [ST]
30. **Eigen, Manfred (hypercycles) [SS]**
31. Foerster, H. , von (cybernetics) [ST]
32. Forrester, Jay (syst dynamics) [ST]
33. **Francois, Charles (encyclopedia) [ST]**
34. Fuller, B. (sys architectures) [ST]
35. **Garajidajeh, J. (sysmanagement) [ST]**
36. **Gel Mann, Murray (flexions) [SS]**
37. **Gerard, Ralph (systems neurosci) [ST]**
38. **Haken, Herbert (synergy, phys) [SS]**
39. **Hall, A.D. (metasystems) [ST]**
40. **Hammond, D. (sys history) [ST]**
41. Holland’s (agent-based modeling) [SS]
42. **Hood, Lee, systems biology [SiS]**
43. **Iberall, A.S. (viable systems) [SS]**
44. **Jackson, Michael (CriticalSM) [ST]**
45. Jantsch, E. (sys philosophy) [ST]
46. **Karplus, M. (syschemistry) [SiS]**
47. Kauffman, Stuart (emergence)[SS]
48. Klir, G. (sys math, fuzzy sets)[SS]
49. **Langton’s (artificial life) [SiS]**
50. Latour (actor net theory) [SS]
51. Laszlo, I. (systems philosophy) [ST]
52. **Leontief, W. (sys economics) [SS]**
53. **Lin, (gen’l systems theory) [SS]**
54. **Lorenz, Konrad (chaos) [SS]**
55. Mandelbrot, B. (fractals)[SS]
56. Maturana, H. (autopoiesis) [ST]
57. Mead, M. (sys anthropology) [ST]
58. Meadows, Donella (sys dynamics) [ST]
59. **Mesarovic, Mihalo (sys biology) [SiS]**
60. **Midgley, Gerald (interventions) [ST]**
61. Miller, James (living systems)[SS]
62. Mitchell, Melanie (complex sys)[SS]
63. Mitroff, Ian (sys management) [ST]
64. Odum, Howard (systems ecology)[SS]
65. **Pattee, H. (hierarch theory) [SS]**
66. Prigogine, Ilya (thermodynamics) [SS**]**
67. Rapoport, Anatol (game theory)[SS]
68. **Randall, Lisa (physics) [SiS]**
69. Richmond, B. (sysdynamics) [ST]
70. Ring, Jack (sys engineering) [ST]
71. **Rousseau, D. (sys philosophy) [ST]**
72. **Salthe, Stan (hierarchies) [SS]**
73. Senge, P. (systems management) [ST]
74. Shannon’s (information theory)[SS]
75. Simms, Jim (quant living sys)[SS]
76. Simons, H.A. (computer systems)[SS]
77. **Skyttner, Lars (chronicler) [ST]**
78. Starkerman, (sys dynamics) [ST]
79. Sterman, (sys dyamics) [ST]
80. Strogatz, S. (chronicler) [ST]
81. Thom, R. (catastrophe theory)[SS]
82. Troncale, Len (sysprocess theory) [SS]
83. Varella, Francisco (autopoiesis) [ST]
84. Vesterby, V. (gen’l sys theory) [ST]
85. Vickers, Geoffrey (sysmanagement) [ST]
86. Warfield’s, John (ISM-managemnt) [ST]
87. **Weinberg, Gerald (sys engin’g) [SS]**
88. Weiner, Norbert (feedback)[SS]
89. **West, Gregory (sys allometry) [SS]**
90. **Whiteside, George (sys chemistry) [SS]**
91. **Wilson, Albert G. (hierarchies+) [SS]**
92. Wolfram, Stephen (math sys)[SS]
93. **Wymore’s, Wayne (sys engin’g) [SS]**
94. **Yam, Y.B. (NECSI, ICCS conf’s) [SS]**
95. **Zadeh, Lofti (fuzzy math) [SS]**
96. **Zeeman (catastrophe theory) [SS]**

One unexpected use of this list is to enable a modest “shock and awe” reaction. It could be used by anyone who feels they are a “systems specialist” or expert to test themselves (as systems engineers and sustainability workers must be by name alone). Can I recognize all the workers? Am I familiar with their work and how it relates to systems? And please remember that this is only an initial, partial listing.

Perusal of this one sample suggests how great is the potential span of available information for systems approaches, whether systems thinking, science, or anything in between often defying simple, exclusive classification. Analysis indicates that several of the workers might be grouped together in what might be called “clusters” or “cohorts” of similar coverages, goals or techniques. The type of information characteristic of each of these clusters in the sample is very different. Placing just some of these names into “alike” work gives an interesting set of cohorts as shown below that could also be used by any self-proclaimed systems expert to do a self-test of which group output they are familiar with and which not. It is an invitation to more learning to all of us and a challenge to the project on unification of systems science of the INCOSE SSWG.

* **SYSTEMS THINKING MEGA-DOMAIN** (less direct use of Scientific Method &/or natural sci expt’s; focus or reliance on logic, philosophy or human application attempts)
  + Original and new systems dynamics (Forrester; Meadows; Senge; Cabrera; MIT)
  + Soft systems methods (Checkland; Flood; Jackson; Midgely; Warfield)
  + Systems management (Ackoff; Ashby; Beer; Churchman; Mitroff)
  + Models based on engineering per se (Wymore; Iberall; Ring; Lloyd)
  + Systems Philosophy (Bunge; Bahm; Laszlo; Bateson; Rousseau)
* **PROTO-SYSTEMS-SCIENCE MEGA-DOMAIN** (exhibits more use of Scientific Method; comparison of and abstraction across evidence from natural sci exp’ts or based on math formalisms) (isomorph means constant & similar abstract patterns of structure or dynamics across the systems of many different domains or disciplines when compared)
  + Original work on GST & Cybernetics (vonBertalanffy; Boulding; Gerard; Weiner)
  + Mathematical systems theory (Klir; Rosen; Rapoport; Thom; SysAnalysis/OR)
  + Isomorph /or/ theory based on science results
    - Models using mostly one systems isomorphy (Prigogine Mandelbrot; per Bak; Corning; Weiner; Thom; West)
    - Models using four or < systems isomorphies (Forrester; Wilson)
    - Models using several systems isomorphies ((Miller (LST Living Systems Theory); Odum; Auyung))
    - Models using a very large number of isomorphies & their influences (Troncale)
  + New systems-integrated natural sciences (much less focus on isomorphies; more on evidence, but whose evidence increases systems understanding)
    - Systems biology (Mesarovic; Allen; Hood)
    - Systems chemistry (Karplus; Whitesides)
    - Earth systems science (Lorenz)
    - Complex Adaptive Systems in Physics (many Institutes & Centers)

We prefer to look at these distinct “areas” as on a spectrum with characteristics and measures varying gradually across the spectrum. In this view, as shown in Figure One, systems thinking is towards one end of the spectrum and the natural systems sciences towards the other end. This perspective has the advantage of placing both “thinking” and “science” on a level of shared characteristics, and not so much as in opposing camps as the historical traditions might suggest.

**sysmgmnt**

**sysphilos “systhink” “sysscience” CSM mathsystheory**



**softsysmeth** **LST** **SPT** **CAS**

**sysbio**

**ISM** **earthsyssci syschem**

**Figure One:** A simple spectrum of systems approach areas from more human to more evidence-based. ST and SS, shown in slightly larger font size as clusters on the single spectrum of development

The reader may want to adjust this spectrum by moving the domains left or right, but based on what? The home cluster of the reader? Their position in the science wars [1,2]? Developing the criteria to guide a consensus on where to place what on this spectrum is an important challenge to the aforementioned INCOSE SSWG Project. For the purpose of this paper we ask, …is all this information across the spectrum truly science-based, which is to say evidence-based? And, as is so often said, why should we care?

3. Juxtaposition: Science & Engineering: Three Short Tests of Whether or Not ST is SS in SE

All words are promiscuous. Just look at a dictionary. Most words have four or five meanings. Of all words, science might be one of the most loosely used with systems close behind. If a field of study or application has the word “science” appended on it, it probably is not science as scientists would define the word. Biology, geology, physics, chemistry – all normally do not have the attachment “science” – and all are indisputably versions of science. But are the widely recognized specialties of design science, management science, behavioural science, and many more, truly science? Further for this article, can their systems focused counterparts be called systems science. Numerous discussions with members of these disciplines show each strongly defends their claim to be science. But even in the sciences there is a pecking order. Physics is the hard science and some may even permit chemistry in that category. Biology and geology were dismissed as mere descriptive specialties in the beginning although now they can clearly claim to be natural sciences. Presumably this would allow results from them to be called a science of systems. But let’s explore that assumption.

* 1. What is science? What is engineering? What is their interrelationship?:

For the purpose of this paper science = use of the scientific method. It has many versions. A recent concept map made by a group of SEs debating the above three questions via SSWG did not look like the science my colleagues and I in cell and molecular biology practiced. Our experimental process involves previous findings, induction of a hypothesized causal chain or alternative mechanisms, isolation of variables by establishing controls, design of an experiment testing the hypothesized mechanism, use of established or innovative techniques and tools to measure experimental outcomes, statistical analysis of measures, coupling conclusions very tightly to the original hypothesis, iteration, reproducibility, and so on. And then there is math, a strong companion of science that does not use experiment at all. Math uses the rules of symbol transformation for each math to discover new relations never before seen. It is truly fascinating that math sometimes predicts relations very long before they are experimentally demonstrated.

Many of the SE-SSWG discussants have strongly protested that engineering is very different from science. Indeed, engineering has much overlap with human need and so has a more anthropocentric orientation than science. You might say engineering is science with a human purpose. By contrast, reference to purpose and goal are generally forbidden in the natural sciences. They introduce the shadow of a divine designer, or human subjectivity and interpretation into what is supposed to be a completely neutral and objective questioning of how nature works. Yet many recognize that much of engineering is based on the results of science. Chemical engineers use chemistry, aeronautical, mechanical and space engineers study and use a great deal of physics and math, and so on. Our cars, planes, phones work reliably because of an engineer’s clever use of science. Also engineering has a central place for testing and evaluation just as science does. So their Venn circles overlap, but not completely.

Presumably systems engineers would need to study system science just as other engineers study the basic science that is the foundation for their applications (as in chemistry for chemical engineers). But what if they only study systems thinking which we discriminate from systems science? Because SEs in many corporations were needed because of the sheer size and complexity of modern engineering projects and products, many SEs study and daily use various systems management and OR tools, techniques and KB. This is clearly needed. Do these aspects of systems thinking include systems science? Would systems science provide additional and significant prescriptive information about the “systems that are built” in contrast to how to “organize humans best to produce a system?” Let’s quick test this in three ways.

* 1. Spot Test One – Recent SE Papers on Systems Thinking (ST) & SE Systems Education

Recently there has been a flurry of papers on teaching systems thinking for SE education in SE-related publication venues [4-8]. How do these papers portray ST versus systems science (hereafter SS)?

Arnold & Wade of the Stevens Institute [4], observe that there is no widely accepted definition of ST, cite and critique those in use, and propose a new one that primarily adds the concept of “purpose” to the features of existing definitions. Their paper clearly describes the importance of systems awareness in solving today’s complex systems-level problems. They quote Forrester that “ST implies a rather general and superficial awareness of systems” but then conflate it with SS that this paper argues could yield a much more detailed and rigorous awareness of systems if adopted by SEs. Although they use ST interchangeably with SS, citing systems science only 3 times, they never define SS as distinct from ST. In fact, they even reduce ST entirely to that practiced by the Systems Dynamics Society and MIT. This ignores a great deal of the literature of the ST mega-domain much less the SS mega-domain. They only cite 4 of the 46 names in ST in our Table One, and zero of the 50 SS lifeworks. They only cite about 5 of the 110 isomorphic systems processes of the SPT (which is intended as a nascent SS). They do not cover the differences between the use of “purpose” or “goal” in human systems thinking relative to its much different counterpart in SS, “function.” This paper provides evidence that ST and SS are conflated in the SE literature and since it is coming from the Steven’s Institute of Technology, a strong SE provider, it indicates that not only is SS neglected in SE, but that even ST is poorly covered.

Camilla & Ferris of the Univ. of South Australia & the Center for SE, Cranfield University have written four papers on the evaluation of ST competencies in SE education [5-8]. Their work is thorough and focuses on a much neglected aspect of both SE & general education assessment – the affective domain relative to what is cognitively learned. While their papers also draw attention to the need for a consensus definition of ST, suggesting another new definition, one of the four does not mention systems science even once (while it does ST nearly 100 times), and the other three of the four mention systems science only rarely (4, 0, 1, and 0 times). Across all four papers, they cite ST 258 times; but cite SS only 5 times. In all of these cases, the usage is in historical contexts; that is, they use SS/ST conflation as some of the historical figures did. Unfortunately, many of the so-called guru’s of systems themselves conflated systems science and systems thinking, in our opinion erroneously. Camilia & Ferris [5] do summarize the entire ST mega-domain admirably. Of their more extensive reference set of 88, compared to our Table One, they cite 18 of our 46 ST lifeworks but only 3 of our 50 SS/SiS lifeworks and for those only the aforementioned conflating guru’s. So while serving a very useful purpose for ST and SE, this paper series neglects SS input as does most of conventional SE. In their conclusion, they state “Our review of the curriculum of 33 institutions in the U.S. and Australia…shows that most institutions do not offer their students a specific ST course.” This author’s survey of the same source indicates that none at all offer a course in SS as defined here and not conflated with ST. Perhaps the origin of the ST-SS conflation this paper argues against can be found in the comparative ignorance of SS by the SE field relative to its dependence solely on ST.

* 1. Spot Test Two Systems Thinking (ST) – INCOSE Pioneers as a Case Study

INCOSE recognized Checkland (2008) and Warfield (2007) as “Founders.” Were they systems thinkers or systems scientists? Both were also Presidents of the International Society for the Systems Sciences (ISSS) [an MOU Collaborator with INCOSE] while this author was Vice President and Managing Director so he interacted with them frequently. Numerous conversations revealed these workers (and other STr’s like Ackoff, Churchman) as strongly ST-based, even opposed to natural science. This is supported by recent summary of ST (such as [4]) where only about 5 of the 110 systems mechanisms of SPT [11-15] are recognized in ST relative to the SPT/SP/SSWG project. That paper’s “functionalist” category is defined as science would be, but groups assigned to it are neither science nor SS according to our criteria. ST has many mechanisms unrepresented (network theory, fractals, natural recycling, self-criticality, symmetries). This would make the ST KB very much weaker and less prescriptive than SS on a general theoretical basis. Yet ST workers continue to cite themselves as SS workers. A quick look at Wikipedia indicates that this conflation of theoretical focus (thinking vs. science) is widespread. For example, Warfield’s last major opus was entitled, *Introduction to Systems Science* [10] showing that he regarded himself as both a systems thinker and a systems scientist. Unfortunately, many in ST do. Meanwhile, for this paper workers strong in mathematics, as was INCOSE Founder W. Wayne Wymore, are midway between ST and SS but because of their strong, necessary emphasis on applied engineering, lean heavily to the ST side.

* 1. Spot Test Three – Systems Engineering Introductory Texts

The Systems Processes Theory that purports to explain how many successful natural systems work using ~110 very defined systems processes and 100’s of linkage propositions between them [11-15 & 18] is the framework SSWG SPT/SP is using to integrate our currently fragmented systems sources (Table One). I examined the index of the latest edition of the SE text by Blanchard and Fabrycky [19] used in many SE core courses. The test was to see how many of the SPT patterns, structures, principles or universal isomorphies (systems processes) were represented in the text. I found brief or tangential mention of five, and more coverage of five others, but completely from a human system or corporation point of view. For example, feedback and control is the best covered, but the discussions of input-output, networks, and purpose are restricted only to corporate coverage. A good example is cycles and cycling; it is covered only in terms of the product(ion) life cycle without any information from the many cycles studied in nature or the immense number of details we have learned from those studies (see [15] for 72 case studies). In summary, compare only human-based coverage of ~5 with 110 in the SPT plus the 100’s of LPs. In fact, the entire spectrum of systems areas cited above was very poorly covered in this fundamental preparation for many SEs. Only 3 of the 96 sources in Table One were cited. Perhaps a dozen pages covered all of systems theory (as a poor stand-in for systems science) at a level that was outdated 50 years ago. A text I would prefer that is still limited would be Hitchins or the new text by Mobus and Kalton [20]. These texts cover more isomorphic systems processes and in greater depth. But still the emphasis in all three basic texts used to educate the new generation of SE’s very poorly represents systems science and is entirely oriented to just one side of the spectrum, systems thinking. While this is entirely understandable and targeted for SE’s, it leaves out rather completely what can be learned from how natural systems have solved the problems of complex systems across nearly 14 billion years of trials and optimization. What systems thinking lacks is the “prescriptive” that is based on scientific evidence and testing in trillions of trials or more.

1. Minimal criteria – for the scientific method, a GST, & for a science of systems

Careful study and selection of criteria for identification and discrimination may be the best start for distinguishing areas like ST and SS. The Founders of GST never did this adequately. Yet it has proven best in the past for such a highly interdisciplinary group as us to debate until a consistent list of criteria are reached before arguing fine points of competing theories and approaches. Criteria can help focus discussion on key issues, improve communication though common terminology, and provide a basis for judgement on inclusion or exclusion in the mega-domains. At INCOSE SSWG International Workshop sessions and ISSS SIG sessions the following criteria lists for a general systems theory and for a science of systems were suggested but consensus was not yet reached.

Criteria for a scientific theory: (1) vast KB consistent with past evidence usually on non-human systems; (2) hypotheses of alternative, falsifiable causalities; (3) prediction(s) from hypotheses; (4) control of variables; (5) experiment to test hypothesized causality; (6) statistical analysis or often involves measurement (empirical); (7) limit conclusion to experiment; (8) cycles of iteration, recursion; (9) evidence so confirmed provides explanatory power; (10) demonstrated predictive power & fecundity; (11) tested by many independent investigators & methods; (12) requirement of replicability; (13) consistent with a wide range of other disciplines (unity & fit); (14) parsimonious; (15) consensus agreement of experts on conclusions; (16) results are correctable; (17) inductive; (18) results discipline use of language or construction of models; (19) often requires invention and calibration of new measurement instruments & tools (20) subsumable; (21) quantifies uncertainty; (22) characterized by strict documentation, archiving, & sharing (23) focuses on phenomena; (24) focuses on natural processes; (25) /or/ involves or enables allowed math formalism transformations. Theories are not laws but may contain several laws. Discovery science and Experimental Science utilize slightly different methods. This is merely a summary; but it gives some basis for deciding whether a practice is systems thinking or uses the science above to explain systems in a scientific manner.

Many of the systems associated disciplines, old and new, that describe themselves as “science” simply do not have all of these characteristics (e.g. design science, social science, behavioral science).

Criteria for a general systems theory included: (1) focuses on finding isomorphisms (patterns consistent across many specific & real instantiations of systems); (2) may be of processes, structures, principles or patterns; (3) protocols for valid abstraction; (4) maps to real systems; (5) high level of abstraction from particulars; (6) has minimal set of isomorphisms defined; (7) describes how the isomorphic processes interact to explain how systems work; (8) can also describe how systems don’t work; (9) describes how systems come into being (origins); (10) explains how a systems fulfils a function or purpose; (11) explains taxonomy of types of systems; (12) provides rationale for identification of system boundaries; (13) defines extents and limits of application; (14) supports or enables modeling and simulation of any real system; (15) must provide evidence of presence of isomorphy across very wide range of types of system. This summarizes a medium consensus between Hybertson & Troncale, reached on Oct 1, 2014.

Criteria for a science of systems (systems science) then would include an amalgam of both lists; the scientific method applied to GST or scientific realism [9].

1. Discrimination: similarities and differences between systems thinking & systems science

While the SPT/SP projects of INCOSE-SSWG would defend the need for ST, it suggests expansion of awareness to SS. Initial lists of some of their similarities and differences might increase understanding of how they are distinct, but also how one could join with the other to employ ALL of the spectrum of systems knowledge to SE.

* 1. An Initial List of **Nine Similarities**: When “systems-level” is added to normal “science”

ST and SS share these similarities to reflect and build upon: (i) Both have the **same universal processes** at work in their systems. I have personally argued this point with many ST gurus (Ackoff; Churchman; Jackson, Checkland, etc). Most believe/teach (often only implicitly) that human systems are entirely different from natural systems. Yet to SS folks, human systems, whether individual, group, or nation, exhibit “hierarchies,” “cycles,” “self-organization,” “feedbacks” “self-criticality,” “equilibria,” “flows,” “fractal structure,” “chaos,” and more as demonstrably as natural systems. How can they maintain that these are different on the systems level? (ii) Both encounter the **same messy problems**, that is, limits on complexity, need for adaptation, dealing with chaos, using chaos, limited resources, and many more. (iii) In the SPT there is a **unbroken continuity of origins**, that is, the chasm between human and animal origins, between the various scales of physical systems, has consistently been bridged by scientific investigation and increased understanding, never the opposite. They are one out of (from) the other instead of one distinct from the other. That is probably why they share the universal processes. (iv) The ultimate success of both is due to dynamic stability and **sustainability** relative to our space:time configuration. (v) Both use the “**comparative**” inquiry style relative to less use of comparative in conventional science. (vi) Both have special need to explain **complexity, emergence, & chaos**. (vii) Both exhibit central role of **non-linear causality**. (viii) Both exhibit a central role for **networks**. (ix) **applications:** the successful case studies of numerous natural phenomena should be considered “applications” even though they are not human.

* 1. An Initial List of **Fourteen Dissimilarities**

But ST and SS have these differences which may have to be overcome, or used as a basis for complementary enhancement: (i) **Main subjects of study:** are different as ST focuses almost exclusively on humans and their institutions or societies; SS on natural phenomena. At the level of particulars, there is no question of difference with natural systems, even biological. The similarities are only revealed in abstracting from, releasing obsession with particulars, to compare how the particulars interact. But it is very difficult for humans to accomplish this release from particulars. (ii) **Measurability:** is much easier in natural systems than humans due to distance from the measuring scale. (iii) **Methods and Tools**: study of natural systems has resulted in extensive innovation of measuring devices and techniques (need we list everything from microscopy to telescopy to spectroscopy & more) that cannot be applied to human behavior. (iv) **Terminology** is quite different because specialties studying human and natural systems have been separated so long. This difference is hard to overcome. (v) What is of **Significance and Value** in each domain of systemness is different. (vi) **Purposes:** ST seeks to improve human systems; SS to research and understand natural systems phenomena as function. (vii) **Uses**: ST emphasizes direct applications while SS contributes to basic research or theoretical understanding. (viii) **Scientific Method**: SS requires rigorous application of the protocols of natural science while ST cannot readily achieve this. Guarantor’s of truth are dramatically different, (ix) **Facts, Results, KB**: SS collects, organizes, archives, curates vast quantities of experimental results called facts; many proponents of ST argue that facts do not exist. (x) **Theory Source:** ST, comes from past attempts to solve human systems problems; in SS from evidence derived from comparing natural systems experiments. (xi) **Objectivity-Subjectivity:** It is easier to test natural science systems in an objective manner while we are the subject of socio-political & engineering studies. (xii) **Determinism vs. Free Will**: Humans are capable of completely ignoring prescriptions while non-human systems cannot. (xiii) **Anthropocentric vs. Ananthropocentric:** Respectively ST vs SS. (xiv) **Limited** **Range of Scales vs. All Scales:** again ST vs. SS when human systems are regarded as natural.

1. Scenarios for Cooperation Between ST and SS

What can we build on to bring these two camps together to help each other in true complementarity? If they are on the same spectrum, they should be able to augment each other to produce a hybrid that has much greater strengths, advantages, and wider application than each alone. Here are five ways that they might build on each other rather than oppose each other.

(1) **Focus on evidence-based prescriptions thru testing: “Translate” from human to natural systems:** the SPT/SP projects of the SSWG suggest these strategies for synergy relative to testing: (i) Engineering places a very high value on testing and evaluation. Recognition by systems thinkers that systems science is backed up by peer-reviewed experiments, and by only selecting commonalities when widely different disciplines, phenomena and scales are compared, may convince some that there is a high degree of testing and evaluation to the SPT prescriptions. (ii) Some progressive human systems thinkers may concede that it is easier to isolate causal influences in natural than human studies. But it is also easier to study chaos and emergence or other non-linear phenomena in natural systems. Again testing wins out. (2) **Focus on problems needing solution:** Both try to solve system of systems problems so can use SPT as a common focus. The linkage propositions between the systems processes lift systems theory to the meta-level of detailed explanation of how systems work thus providing a tool to address the complexity issue faced by engineering. How to make systems adaptive is a modern problem for engineers (as is how to handle emergence). Natural systems have encountered and solved this across 14 BYs (see recent biomimicry, systems mimicry NSWG (Natural Systems Working Group) Webinar). (3) **Focus on isomorphic systems processes and pathologies**: and their multiple simultaneous influences. SPT is based on recognizing the isomorphic systems processes that lead to universal patterns in both natural and human systems when studied on the abstract level. They demonstrate the same systems archetypes or architectures in SE terms. This give much hope for ST moving to SS. The SPT/SP framework and synthesis provides an unprecedented level of detail in its 110 SPs and 100’s of LPs to explain how systems work for SEs, its spin-off, systems pathology [18], recognizes many systems dysfunctions not known in SE. (4) F**ocus on modelling and simulation:** If SSWG is able to verify a general model of models, it may be of practical use for many specific models made by INCOSE-SE & MBSE-WG (Model-Based SE). (5) **Vet alternative frameworks for synthesis**, integration, & unification to enable the synergy that is likely between a widened ST perspective, and SS.

1. Summary/Conclusion

What we need is a list of consensus criteria on what constitutes “science” or not to use in distinguishing thinking from science as regards systems level awareness and approaches. Arguing over and coming to agreement on individual criteria to include is less partisan and more amenable to compromise than arguing directly about the designations. This paper is a call for a “criteria” debate across both the thinking and science communities that would lead to a mutual consensus and communication.

A useful and convenient surrogate for all of the above is to use the extensive peer-reviewed literature of the several natural sciences (astronomy, physics, chemistry, geology, biology, computer science, & mathematics). Results reported in these for a very wide range of non-human phenomena, when properly abstracted, would necessarily exhibit all of the above criteria and yet be evidence for how systems work or don’t work at a very fundamental level (the level of isomorphisms). The extensive list of such “proven design” isomorphies in prototype systems sciences (such as SPT, Systems Processes Theory) [12-15] would provide a valuable, list of specifics as a checklist for SE designs and testing. A further “failsafe” is the demand that these abstractions be compared for similarity and consistency. It is likely that an observed process or pattern proven across many natural science disciplines and phenomena, observed in a wide range of scales of system, originating at widely different times, by different mechanisms, across disciplines, studied by independent and differing tools and techniques, and different investigators would hold true for improving SE designs.

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