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Note to reviewers: *apologies. I had four co-authored papers to submit by deadline. This was the last and so was still incomplete by time of submission. Needs 1 section & 1 subsection and ref's to complete. And I have yet to contact co-author "Bud" Lawson. Hope you have enough to say go or no go. Thanks.*

From Systems "Thinking" to a Science of Systems Processes Engineering: Similarities, Differences, Synergies

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Abstract

This paper is based on observations that while systems engineers are currently increasing their knowledge, appreciation and use of systems, they remain virtually unaware of the riches available for SE from the natural systems sciences. The core purpose of the paper is to clearly discriminate between the often-conflated terms, "systems thinking" and "system science." Our projects of the INCOSE-SSWG are trying to do this by developing a framework to help integrate the very fragmented areas of systems approach. We cite a long list of different systems approaches (domains) as sources that need to be unified and develop the idea of these being on a definable spectrum with "thinking" near one extreme and "science" the other. We will suggest several distinct differences between "thinking" and "science," but also include several similarities that could become the basis for synergy using the systems process of complementarity. The result would be a more rigorous SE with much wider applications.

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1. Statement of the problem: Need to Address Directly

Systems Thinking is a phrase often used in the systems engineering field. In fact, this series of conferences (CSER)[1] as well as the recent LA Mini-Conference[1] seemed to use the term exclusively to represent SE interests in the systems approach. The work and workers cited for this systems thinking are clearly needed 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 huge, as yet 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 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. One purpose of this paper is to directly counter the conflation of the terms systhink & sysscience.

1.1. Background of the problem; a 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,[2] but they use different tools, methods, and have different guarantors of truth. To a group of systems-interested advocates such as this audience, I hardly have 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 I began my 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. In the nineties, there was a public outbreak of articles in major journals representing both sides. Post modernists[3] stated logical positivism and reductionism was dead and did not produce factual knowledge, but rather knowledge was socially constructed and so inherently subjective and human-based. Scientists[4] 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. They saw such fields as cultural anthropology, literature, some 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 webinars to INCOSE engineers,[5] I have found representatives of both of these camps.

1.2. 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 real 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 each 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.

1.3. Need for a unified systems knowledge base and an expanded view of systems engineering:

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, on Systems Processes-Systems Pathologies (SP/SP)[6] 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.[7] Second, we will use a framework of how systems work (systems processes) and how they don't work (systems pathologies)[8] 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 products but to curate and repair a wide range of natural systems 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 in an environment of hostility between a human-based systems thinking and a natural science based systems science?

2. Viewing Systems Areas as 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 knowledge base for systems science. In just a 30-minute time period they produced a list of 54 via open brainstorming.[9]

The author of this report was moderator of the Workshop so did not submit his own candidate names. His "top of the head" memory additions (33 unique names, shown in bold) represents only a partial list of those he considers important. Adding them together (Table One) gives an initial list of 87 lifeworks that need to be synthesized! This task is one of the official projects of an ongoing SIG of the ISSS and of the aforementioned INCOSE SSWG whose work is now connected by a memo of understanding between the two professional organizations.[10]

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Table One: Lifework in Systems to be integrated: Output of ISSS'13 Workshop, July x, San Jose, Ca. (Obviously citations for each of these would take more space than this article).

1. Abraham, Ralph (chaos math)	**6. Bak, Per (self-criticality)**
2. Ackoff, Russell (sys mgmnt)	7. Bar Yam, Yaneer (NECSI products)
3. Allen, Tim (hierarchies)	8. Barabasi, A.L. (network theory)
4. Ashby, Ross	**9. Barrow, John D. (physics)**
5. Auyung, Sunny (complex systems)	10. Beer, Stafford

11. Bertalanffy, Ludwig von (GST)
12. Bosch, Ockie (bayesian stats)
13. Boulding, Kenneth (GST & econ)
14. Capra, Fritiof (systems philosophy)
15. Checkland's, Peter (soft systems)
16. Churchman's, C. West (sys mgmnt)
17. Corning, Peter (synergy, bio)
18. Cowan's,
19. Earth systems science (as a field)
20. Eigen, Manfred (hypercycles)
21. Forrester, Jay (syst dynamics)
22. Francois, Charles (encyclopedia)
23. Garajidajeh, J. (sys management)
24. Gel Mann, Murray (flexions)
25. Gerard, Ralph (systems neurosci)
26. Haken, Herbert (synergy, phys)
27. Hammond, Deborah (sys history)
28. Holland's (agent-based modeling)
29. Hood's systems biology,
30. Iberall, A.S. (viable systems)
31. Jackson, Michael (SSM)
32. Kauffman, Stuart (emergence)
33. Klir, George (sys math, fuzzy sets)
34. Langton's (artificial life)
35. Lazlos' systems philosophy,
36. Lorenz, Konrad (chaos)
37. Mandelbrot, Benoit (fractals)
38. Meadows, D. (sys dynamics);
39. Mesarovic, Mihalo (sys biology)
40. Miller, James (living systems)
41. Odum, Howard (systems ecology)
42. Pattee, Howard (hierarch theory)
43. Prigogine, Ilya (thermodynamics)
44. Rapoport, Anatol (game theory)
45. Randall, Lisa (physics)
46. Salthe, Stan (hierarchies)
47. Senge, Peter (systems management}
48. Shannon's (information theory)
49. Skyttner, Lars (chronicler)
50. Thom, Rene (catastrophe theory)
51. Troncale, Len (sysprocess theory)
52. von Foerster, Heinz(self-organiz.)
53. Warfield's, John (ISM)
54. Weinberg, Gerald (sys engin'g)
55. West, Gregory (sys allometry)
56. Whiteside, George (sys chemistry)
57. Wilson, Albert G. (hierarchies)
58. Wymore's, Wayne (sys engin'g)
59. Zadeh, Lofti (fuzzy math)
60. Zeeman (catastrophe theory)

One unexpected use of this list is to induce a modest "shock and awe" reaction. It could be used by anyone who feels they are a "systems specialist" or expert to test themselves. 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 a science of systems. Analysis indicates that several of the workers might be grouped together in what might be called "clusters" or "cohorts" of similar facts, goals and 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.

- soft systems methodologies & systems thinking (Checkland; Jackson; Warfield; Starkerman; Senge)
- mathematical systems theory (Klir; Rosen; Rapoport)
- theory/models using a single systems process (Forrester)
- theory/models using many systems processes (Miller; Odum)
- applications to engineering per se (Wymore; Iberall; Ring
- natural science focused on a single systems process (Prigogine; Mandelbrot; per Bak; Corning; Weiner)
- natural science focused on several systems processes (Auyung)

- general systems theory (Boulding; Gerard; von Bertalanffy)
- systems biology (Mesarovic; Allen; Hood)
- systems chemistry (Karplus; Whitesides)
- earth systems science (Lorenz)
- systems management (Ackoff; Churchman; Mitroff)
- systems philosophy (Laszlo)

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.

Figure One: A simple spectrum of systems approach areas from more human to more evidence-based. ST and SS, topics of paper, shown in larger font size.

Now the reader may want to adjust this spectrum by moving the clusters left or right, but based on what? The home cluster if the reader? Their position in the science wars? 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: Systems Thinking, Systems Science, Science, Engineering

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. 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, or behavioural science, and many more, truly science? Further for this article, can their systems counterparts be called systems science. I can tell you from numerous discussions in the past that each of these is vociferous in 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.

3.1. 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.

Many of the SE-SSWG discussants[11] 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. They introduce 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 and mechanical engineers study and use science 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. But what if they only study systems thinking which we discriminate from systems science below? Because SEs in many corporations were needed because of the sheer size and complexity of modern engineering projects and products, many SEs study and use daily various systems management tools, techniques and KB. This is clearly justified. Is then systems thinking the same as systems science or could a broader knowledge of 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 reflect on this using two quick "tests."

3.2. Spot Test – Systems Thinking – INCOSE Founders:

Cite here advantages and limitations of Warfield, Checkland,

3.3. Spot Test – A Much Used Systems Engineering Text:

The Systems Processes Theory[8] that purports to explain how many successful natural systems work using ~50 very defined systems processes and 100's of linkage propositions between them is the framework SSWG SP/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[12] used in many SE core courses. The test was to see how many of the SPT patterns, 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 studies in nature (see[13] for 52 case studies). In summary, compare <5 with 50 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 87 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.[14]

3.4. Minimal criteria – for the scientific method – for a GTS – for a science of syste

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. ((Place here my criteria lists developed independently and then those agreed on with George

Klir. Use description above of scientific method as minimal criteria for it. And then expand to new work listing criteria for science of systems citing past paper.))

4. Similarities and Differences Between Systems Thinking and Systems Science

While the SP/SP project would defend the need for systems thinking, it suggests expansion of awareness to systems science. Citing an initial listing 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.

4.1. An Initial List of Similarities:

Systems thinking and systems science 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 systems thinkers (Ackoff; Churchman; Jackson, etc). They believe (emphasis on belief) that human systems are entirely different from natural systems. But what human systems, whether individual, group, or nation, do not show "hierarchies," or "cycles," or "self-organization," or "feedbacks" or "self-criticality," or "equilibria," or "flows," or "fractal structure," or many more. How can they maintain that these are different on the systems level? (ii) Both encounter the **same knotty 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 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.

4.2. An Initial List of Differences:

But systems thinking and systems science have these differences which may have to be overcome, or used as a basis for complementary enhancement if we become sufficiently sensitive to them. (i) **Main subjects of study** are different as systems thinking focuses almost exclusively on humans and their institutions or societies. 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 then humans due to distance from the measured scale. (iii) **Methods and Tools** – study of natural systems have resulted in extensive innovation of measuring devices and techniques (need we list everything from microscopy to teloscopy to spectroscopy and more) that cannot be applied to human behaviors. (iv) Since the disciplines studying human and natural systems are so separated for so long, it is natural that their **Terminology** is quite different. This difference is hard to overcome. (v) What is of **Significance and Value** in each domain of systemness is different.

5. Scenarios for Cooperation Between Systems Thinking and Systems Science: Synergies

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.

5.1. Focus on Evidence-Based Testing:

We in the SP/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 principles. (ii) Even the most isolated human systems thinker 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.

5.2. Focus on Problems Needing Solution:

We in the SP/SP projects of the SSWG suggest these strategies for synergy re: problems needing to be solved: (i) Both are focused on system of systems problems. The natural systems sciences and SPT regard all entities essentially as SoS. (ii) 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. (iii) How to make systems adaptive is a modern problem for engineers (as is how to handle emergence). Natural systems have encountered and solved this through 14 billion years of problem solutions.

5.3. Focus on systems processes and their multiple simultaneous influences:

We in the SP/SP projects of the SSWG suggest these strategies for synergy relative to use of the systems processes and systems pathology framework for integration across systems areas shown in Figure One: (i) As described above both natural and human systems when studied on the abstracted level demonstrate the same systems archetypes or isomorphies. This give much hope for ST moving to SS. (ii) The SP/SP framework and synthesis provides an unprecedented level of detail in its 50 SPs and 100 LPs to explain how systems work for SEs. (iii) the accompanying systems pathology recognizes many systems dysfunctions not known in SE.

5.4. Focus on modeling and simulation:

We in the SP/SP projects of the SSWG suggest these strategies for synergy through use of the modelling and simulation that is key to both SE and SS: (i) ; (ii) ; (iii).

5.5. Focus on vetting frameworks for the unification task:

We in the SP/SP projects of the SSWG suggest these strategies for synergy relative to our declared task of integration of a wide range of systems sources: (i) ; (ii) ; (iii).

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