The Future of Systems X?
If you want a better Systems X discipline or program, upgrade your Systems Thinking to version 4.0

Derek Cabrera[a,c,d], **Laura Cabrera**[a,c,d], **and Graeme Troxell**[a,b]

[a]Cornell University; [b]Cornell Engineering; [c]Cornell Human Ecology; [d]Cabrera Research Lab

Abstract: Systems Thinking is it's own scientific disciplinary field, but it is also a meta-discipline that acts as a prefix for other fields such as: systems science, systems engineering, systems neuroscience, systems design, systems biology, system dynamics, systems evaluation, systems education, systems leadership, systems mapping, and systems research, and many more that don't follow the strict naming convention but which are effectively doing the same thing such as: developmental systems theory, family systems theory, human ecology, and the list goes on. Integrating systems thinking into a discipline, or a program responsible for anointing degrees in such discipline is more difficult. It requires consideration of both the depth and breadth of content. This impacts the disciplinary field , and also the programs designed to teach that content from a ST lens. As a result, many scholars are seeking a better understanding of what a systems thinking is, and what it means to embed ST into their academic discipline. This paper offers principles that underlie the fourth wave of systems thinking as a field; and also applies them to the design of education programs in any field that includes an emphasis on systems, systems thinking, or a systems lens. Delineating the case example of Systems Engineering yields a specific formula for allocating educational effort used to better design programs for a long term value to both the fields and its graduates.

systems thinking | DSRP | Systems Engineering | Systems X | version 4.0

1. The Future is Systems X

Systems Thinking (ST) is its own discipline, but it has become a *meta-discipline*—a discipline that is *applied to* and *transforms* other disciplines. As an expert is Systems Thinking, I am often asked to assist in the process of applying "Systems Thinking" to "*Discipline X*" to yield "*Systems X*" (e.g., Systems Engineering, Systems Evaluation, etc.). Usually, the implication of such an action usually play out in one or more metaphors:

- We must use Systems Thinking as the *foundation* for Discipline X;
- Systems Thinking is a *lens* on Discipline X;
- Systems Thinking and Discipline X are a portmanteau, a *marriage* that creates the love child, Systems X; or
- Systems Thinking is like the *carpentry skills* and the rest of Discipline X is the tools.

No matter the metaphor, the idea is that by tacking Systems Thinking onto the front of Discipline X, Systems Thinking will *modify* and *transform* Discipline X. It is today common practice in the disciplines to rejuvenate a struggling or ineffectual discipline or to propel a vital existing discipline into the future by considering the impact the modifying adjective "Systems" might have on it, as in "Systems X." There are countless examples of Systems Xs, including: systems science, systems engineering, systems neuroscience, systems design, systems biology, system dynamics, systems evaluation, systems education, systems leadership, systems mapping, and systems research, and many more that don't follow the strict naming convention but which are effectively doing the same thing such as developmental systems theory, family systems theory, human ecology, and the list goes on. For as many X as there are, there are an equal number of Systems X. Indeed, the influence of a "systems

Significance Statement

The significance of this paper is four-fold: (1) generally, to establish the idea of Systems X, a portmanteau of Systems Thinking and Discipline X; (2) specifically, to differentiate and quantify the difference between the field of of Systems Engineering and other Engineering fields; (3) to use this differentiation and quantification to highlight the need for an integral, foundational role that Systems Thinking plays and contrast that from a "tack on" role, and; (4) to clarify for the reader the difference in versions of systems thinking that might be chosen (i.e., between STv1.0 and STv4.0).

[2]Address correspondence to E-mail: Derek Cabrera dac66@cornell.edu

approach" is currently so pervasive that even in fields that aren't considering a formal name change or differentiated field (e.g., Systems Engineering is differentiated from Engineering) there are internal transformations going on. To one degree or another, in all of the major disciplines—Physics, Chemistry, Biology, Psychology, Sociology, Economics, Business, Policy, Education, Agriculture, etc.—the Systems Thinking (ST) lens is upsetting the apple cart.

Not long after Systems Thinking has taken root in the discipline (sometimes too long), people begin to take up the issue of education and training. The thinking goes something like this:

- If Systems Thinking modifies X in PDQ ways to make Systems X, how do we ensure that an education or degree in Systems X develops the necessary skills?
- Indeed, how does Systems X compete with X?
- How might Systems X influence X?
- How is Systems X different from X?
- And, how can Systems X prove its value to X?

Many of these questions are existential in nature—what *is* this new Systems X? But, deeply connected to these existential questions are pedagogical (or parental) ones—How do we raise our students to be competent (and differentiated) purveyors of Systems X? Each of these existential questions has yet to be addressed in detail in most Systems X programs (not the least of which is Systems Engineering, which we address in our case example). And, I am unaware of any serious, concerted, systematic effort to resolve them.

Systems Engineering is perhaps one of the best examples of this struggle for a number of reasons. First, because as a field, engineering is well respected. The thinking is, if engineering is applying systems thinking to itself, then it must be something worth doing. Second, the types of problems engineers (like so many other disciplines) are facing are changing. Problems are increasingly complex. Thus, external natural forces like increasing globalization and interconnectivity influence the need/desire for a "systemy" version of this powerhouse discipline. Third, engineering is a good example because there are formal Engineering departments around the world, many of which have Systems Engineering (SE) components (departments or divisions). Their job is not only to contribute to knowledge but also to train new Systems Engineers. Their role is therefore predicated not only on deeply understanding what SE is but also what it must become. They concern themselves with questions about how they must train current students for a future that is rapidly changing. The discussion below will therefore center around SE, but it could equally be applied to any Systems X (SX).

2. Define SE and SE education more precisely

Systems Engineering (SE), as it exists today, might be anecdotally broken into three camps:

1. SE is just good engineering (i.e., there is no substantive difference between Engineering and SE, SE is just a name for what good engineers naturally do). This camp is widely populated by older traditional engineering professors.
2. SE is an effective approach to managing engineering teams; a camp typically populated by engineers looking for promotion to upper management at premier engineering organizations.
3. SE is a meta-discipline (i.e., a qualitatively and quantitatively different animal than traditional engineering disciplines). This camp is populated by some systems engineers and people who focus on complex systems design.

Of course, there is some truth to all of these "cultural camps." Camp 1, for example, is perhaps in an ideal world accurate, but programs that "fly this flag" often lack the explicit development of systems thinking in the engineering program, which is devalued in the interest of physical and quantitative rigor in the classic reductive sense. This has led to generations of engineers who can't effectively engage with real-world complexity, which they either ignore or hastily over-simplify. The second camp, while having some truth, leads to the current reality where many universities offer SE as essentially a business management degree for practicing engineers. In doing so, it neglects to recognize the vast scholarship and practice in both leadership generally and in systems leadership specifically. Programs that desire to inculcate these skills should "lean in" and work toward a legitimate new field—a programmatic portmanteau of *Systems Leadership* + *Engineering Leadership*; a field that we suggest should be called "Systems Leadership in Engineering" and which deserves its own treatment and therefore won't be covered here. But, if Systems Engineering (or Systems X of any flavor) is to be taken seriously, it must develop in such a way as to focus on the third camp. To do so, this discipline needs to be better defined.

We use some math here for two reasons: (1) to be more precise about our definitions and (2) because determining what goes into a training curriculum in Systems X is determining the amount of time spent on "pdq" topics. The typical approach has been to take whatever training is currently provided by X and simply add Systems Thinking to it. This is infeasible for two reasons:

First, the resulting curriculum in SX cannot be significantly larger/longer than that of X. If, for example a student is getting a four year degree in X, they will also get a four year degree in SX. It isn't reasonable or sustainable to stuff 6 or 7 years worth of expertise and skill into 4 years. Or if you teach a single semester course in SX to parallel one of your colleague's courses in X, you only have one semester to fit all that content within that time period.

Second, this type of thinking (that we can simply stuff more into SX), causes ST to become a "tack on" addendum to SX. An awkward and precursory appendage. What we have learned about the training of ST is that learning requires a great deal of unlearning to occur. A simple prerequisite course of ST is likely never going to be enough. Authentic and effective SX programming requires *integration throughout.* If ST is "tack on" your program is doomed to fail from the start.

Thus, the math helps us to keep track of the specific definitions as well as quantitative realities and limitations of designing programs. The math is quite simple. One of the goals of any Systems X (SX) is to define itself. Another goal is to define what constitutes adequate training in SX.

Systems Engineering (SE)—one form of SX— is no different. Engineering (E) can be defined[*] as equal to Civil Engineering (CE) + Mechanical Engineering (ME) + Electrical Engineering (EE):

$$E = CE + ME + EE \qquad [1]$$

An outgrowth of Engineering, Systems Engineering (SE), can be defined as Systems Thinking (ST) plus Engineering (E):

$$SE = ST + E \qquad [2]$$

The "T-model" of education is a simple model in which the horizontal bar of the T represents breadth (b) in the topic/discipline whereas the vertical bar of the T represents depth (d) in the topic/discipline(1).

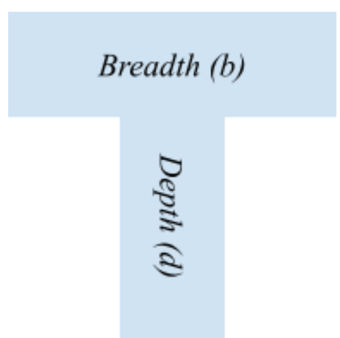

Fig. 1. The T-model accounts for degrees of breadth (b) and depth (d).

Breadth (b) might include things like: the various areas of the discipline and how they interrelate; a survey course in the topic/discipline; a history of the discipline; how the topic/discipline works as a whole; or a cursory review of any aspect of the topic/discipline for the purpose of developing awareness of its existence, etc. Whereas, depth (d) might include a specific, detailed, dive into any given model; the specific skills or steps involved in using a particular tool, method, or technique; or coverage of any aspect of the topic/discipline for the purpose of developing deep mastery in that relatively small area, etc.

The T-model transforms the formula for Systems Engineering education (SE_e) to the sum of knowledge/skill development in Systems Thinking (ST) at a given breadth and depth plus knowledge/skill development in Engineering (E) at a given breadth and a depth, expressed as:

$$SE_e = \sum ST(b+d) + E(b+d) \qquad [3]$$

We can then assign breadth (b) and depth (d) a number on a scale from 0-10; where, 0 denotes no knowledge/skill and 10 denotes expert-level knowledge/skill (see Table 1). Note also that the average knowledge/skill of a well-trained beginner would be a 5 (i.e., equivalent to a four year degree in the field from an accredited university or college).

[*] One could if they desired include other forms of engineering here (chemical, aerospace, etc.) as this basic equation is additive. Different programs define it differently, however, most programs include the "big 3."

Table 1. Quantifying the T-model's breadth (b) and depth (d) variables

0	5	10
No skill or knowledge in the topic/discipline	The amount of skill or knowledge in the topic/discipline typically associated with a four year degree from an accredited college or university program	The amount of skill or knowledge in the topic/discipline typically associated with "expertise that comes with >10 years of real-world experience

In order to define a Systems Engineering education (SE_e) curriculum we must allocate time to both breadth (b) and depth (d) in both Systems Thinking (ST) and Engineering (E). In visual terms, this might look like Figure 2[†], where the core competencies of SE are balanced between ST and E:

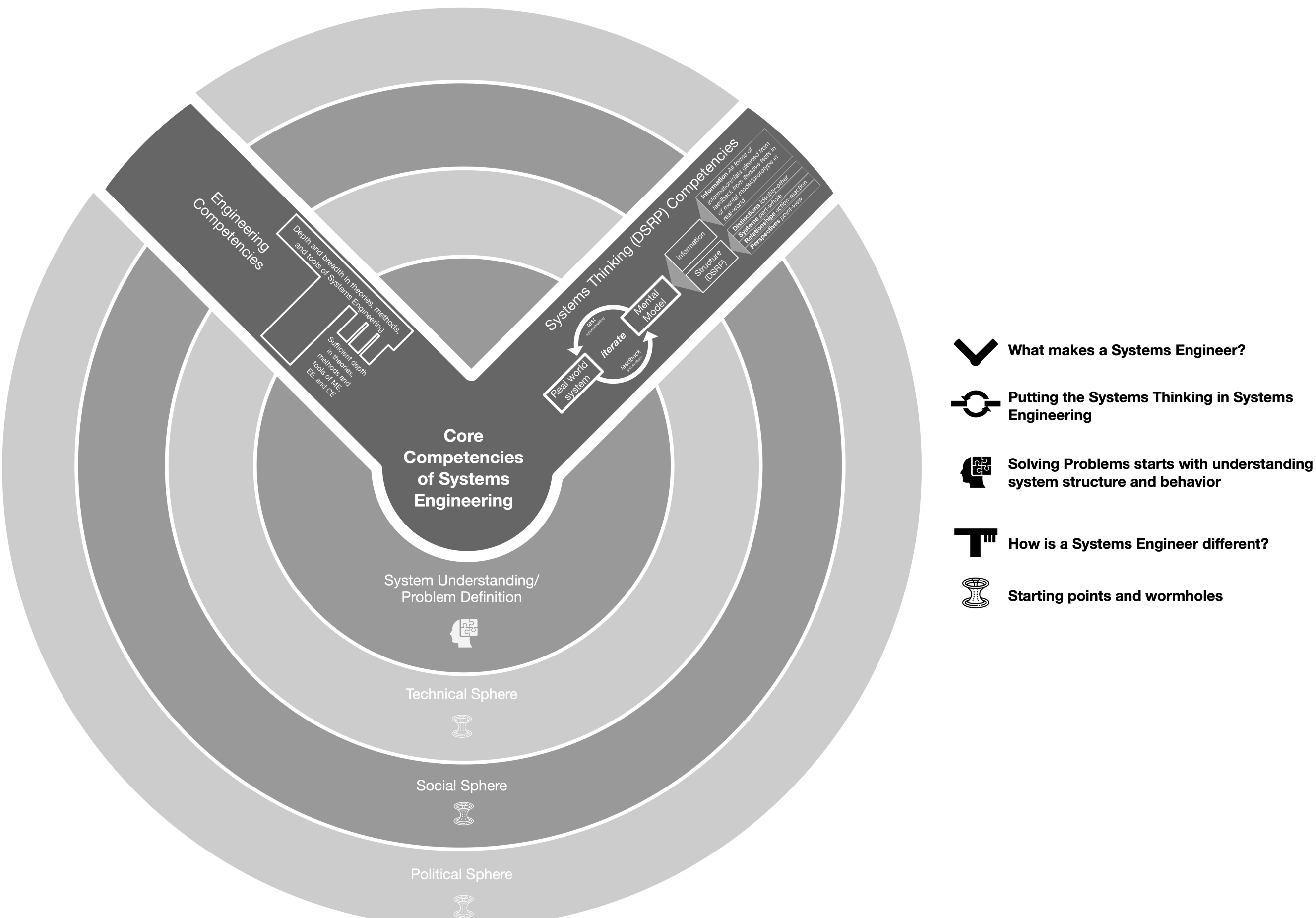

Fig. 2. SE Model explicating depth and breadth in ST and E

Note that the core competencies of Systems Engineering are balanced between Systems Thinking and Education based on breadth (b) and depth (d) as seen in Figure 3:

[†] This model was developed by Cabrera and Gibson, et. al. and first appeared in (2). Gibson(1) (p95) expands on the variance in the depth of ST + E. This is further examined as a model in Systems Leadership in Engineering(3)

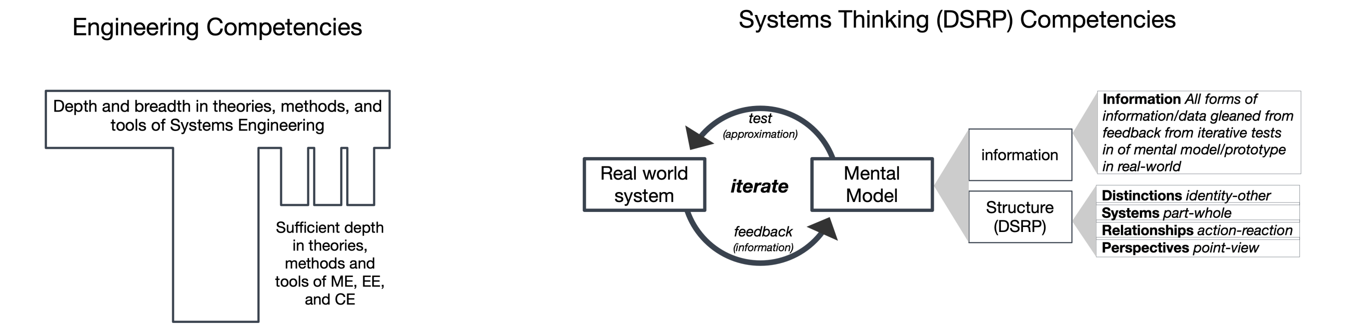

Fig. 3. Zoom in to breadth (b) and depth (d) of ST and E

In contrast, a typical, traditional Engineering education (XE_e)— or a degree specializing in CE, ME, or EE—is defined as XE at a given breadth (b) and depth(d); or

$$XE_e = \sum XE(b + d) \quad [4]$$

For reasons explained earlier in this paper, an education in Systems Engineering (SE) cannot be significantly greater ($\ngtr\ngtr$) in net units of effort than an education in XE. Ergo:

$$SE_e \ngtr\ngtr XE_e \quad [5]$$

This is because we cannot simply say that a student of SE is going to gain everything a student of XE masters in the same period and also gain another whole set of skills and knowledge associated with ST. We can, perhaps, expect some additional amount, but it cannot be significantly greater.

Let's also assume that no education (XE_e or SE_e) can exceed a value of 5 in either depth or breadth accounting for the empirical understanding that true expertise (max of 10) requires time and experience (i.e., >10 years).

A traditional Engineering degree (XE_e)—one that specializes in CE, ME, or EE—can be quantified as follows: XE at a breadth of 2 and a depth of 5. This means, for example, that a traditional degree in Mechanical Engineering (ME) will focus on developing a great deal of depth in mechanical engineering knowledge/skills while perhaps providing a cursory introduction to other forms of engineering. A traditionally trained ME will leave school with a good handle on ME and a very cursory knowledge of all the other engineering approaches, problems, and knowledge; or, where XE=1,

$$XE_e = \sum XE(2 + 5) = 7 \quad [6]$$

This means that the graduate of this program developed a depth of 5 and a cursory breadth of 2, where a seasoned expert with many years experience in the field might be at a breadth of 10 to engineering writ large and depth of 10 for mechanical engineering. Thus yielding 7 (out of a possible 20).

If an XE_e degree is on average, a combined score of depth and breadth of 7, then the most an SE_e (degree) should expect should not exceed 7. So, assume that a hypothetical SE_e degree program is also a 7 based on breadth and depth allocations. Thus, if an SE degree is a balance of ST and E, then the equation would include a total of 3.5 for each ST and E. This means 0.5 of breadth for each ST and E and a depth of 3 for each as follows:

$$SE_e = \sum ST(0.5 + 3) + E(0.5 + 3) = 7 \quad [7]$$

Remember that this same equation can be used to shed light on a systemic lens placed on a discipline, such as systems science, systems evaluation, systems neurobiology, systems leadership, and others—all of which fit this equation:

$$SX_e = \sum ST(0.5 + 3) + X(0.5 + 3) = 7 \quad [8]$$

The question SE (and SX) educators should be asking themselves is one of satisficing balance. The available range is: $SE_e = \sum ST(0.0) + E(7) = 7$ to $SE_e = \sum ST(7) + E(0.0) = 7$. Where in the equation on the left you have all of the available units of effort (7) on the Engineering side and in the equation on the right you have all of the available units of effort (7) on the Systems Thinking side. Obviously we'd want to find something more balanced. Thus, where Engineering and Systems Thinking emphasis is equal (3.5 each), the middle value on the continuum is:

$$SE_e = \sum ST(3.5) + E(3.5) = 7 \qquad [9]$$

Of course, there are also balance ranges within ST and E, such that you can ratchet up the breadth and depth in ST or in E or both to identify the right balance. Note again that the sum should not exceed a reasonable number (e.g., 7) that is comparable in effort, time, and resources to other "non-systemic" programs. In the equation below, every position where there are up and down arrows ($^{\uparrow}_{\downarrow}$) indicates a place of variation in the curriculum

$$SE_e = \sum ST^{\uparrow}_{\downarrow}(b^{\uparrow}_{\downarrow} + d^{\uparrow}_{\downarrow}) + E^{\uparrow}_{\downarrow}(b^{\uparrow}_{\downarrow} + d^{\uparrow}_{\downarrow}) = 7 \qquad [10]$$

Table 2 below shows the differences between an SE Education Curriculum and an XE Education Curriculum based on allocation of effort (time and resources) on a topic. In addition, these are suggested up and down allocations for SE.

Table 2. Note the differences in programmatic focus based on arrows where breadth (b) and depth (d) values are increased (↑), decreased (↓), or balanced (↔).

Suggested SE Education Curriculum	Typical CE, ME, or, EE Education Curriculum
$SE_e = \sum \overleftrightarrow{ST}(b_{\downarrow} + d^{\uparrow}) + \overleftrightarrow{E}(b^{\uparrow} + d_{\downarrow}) = 7$	$XE_e = \sum E(b^{\downarrow} + d_{\uparrow}) = 7$

Filling in values for the suggested program in SE above, we suggest that a starting assumption can reasonably be made based on both anecdotal and empirical evidence that the satisficing values for an SE education curriculum should be as follows on Table 3:

Table 3. Different Programmatic focus of breadth (b) and depth (d) for given values in an SE or CE, EE, or ME Curriculum.

Suggested SE Education Curriculum	Typical CE, ME, or, EE Education Curriculum
$SE_e = \sum ST(0.5 + 3) + E(3 + 0.5) = 7$	$XE_e = \sum XE(1 + 6) = 7$

We set a typical XE program for comparison using equal summative values for both programs (7). Thus, it is suggested that a Systems Engineering education (SE_e) curriculum allocates knowledge/skill development in systems thinking (ST) is at a breadth of 0.5 and a depth of 3 plus the knowledge/skill development in Engineering (E) is at a breadth of 3 and a depth of 0.5 (where expert knowledge is a 10 and the educational maximum in depth or breadth is 5). *In other words, we differentiate the engineering aspect of an SE degree from an XE degree by flipping the balance of breadth and depth* The engineering knowledge/skills in an SE degree favor breadth over depth on the engineering side and favor depth over breadth on the systems thinking side.

Balancing of depth/breadth using the "T model" of expertise articulated above; where the horizontal bar of the T represents breadth and the vertical bar represents depth in a particular area. Note that the scale applies to both breadth and depth, thus a seasoned expert with breadth and depth would reach a maximum "T-score" of 20 and the absolute maximum assumed for a superstar graduate of an accredited four year program would be a "T-score" of 10.

The exercise we walked through truly defines—by way of comparing and contrasting similarities and differences—the difference between a "systems engineer" and an "engineer."

SE programs—and all SX programs—must make a conscious choice of the *version* of Systems Thinking (ST) they will offer. There are multiple versions of ST offered within the ST Field itself, and some may be more effective than others. Ironically, many programs attempt to propel their disciplines and curriculum into the future (and prepare their students with future-ready skills) by choosing Systems Thinking models from the past, which thwarts their best efforts to advance their programs.

It should be noted that the proposed balanced-formula in [9] is an idealized program which assumes some things about real-world programs that are often *not* the case. It assumes for example that if the program is balanced, so too the faculty would be balanced, as would time-on-task, resource-allocation, etc. Yet, few if any faculty members will have been formally trained in Systems Thinking (akin to their formal training in Engineering, for example) to the degree necessary to achieve a true balance where the depth of ST = 3. This means that balance, even if acknowledged as necessary, will be hard to establish outright without hiring new, systems-focused faculty. Second, many of the prestigious journals and conferences in traditional disciplines are somewhat averse to systems-based approaches unless those approaches adhere to established expectations. Disciplines that have gotten accustomed to mathematical precision are less inclined to accept more holistic (and, as a result, more "ambiguous") results from systems-based approaches, even if the latter are legitimate and insightful accounts of the real world. A question that needs to be settled across engineering, then, is whether SE is adjacent to XE programs or "above" XE programs. The answer will determine whether SE can publish in traditional journals, or only in SE-focused journals—and, ultimately, how much exposure XE gets to SE.

In addition to "balancing" the SE equation to be equal parts ST and E, there is the issue of *orientation*. The idea that depth in ST is simply additive rather than integrative is important. An additive approach alone will improve existing SE programs. And, it is conceivable to imagine that the depth and breadth curriculum in ST could be relatively uniform across not only SE programs but all Systems X programs. This is occurring today in many Systems X programs using DSRP-Systems Thinking. However, ideally speaking, the ST content itself is better received if it is "engineering-ish" in its orientation. this often requires better oriented case studies, activities, projects, project rubrics, lecture content, and the like, which are geared toward the particular genre of Systems X.

3. Systems Thinking version 4.0

As noted previously, Systems Thinking has gained popularity and promise as a meta-discipline because of natural forces. This is true, as increased complexity wrought by globalization (or increased interconnectivity) has made problems more wicked, systems more complicated, issues more interdisciplinary, and people more befuddled. Natural forces have been a boon for ST as a discipline. But along with these natural forces (but to a far lesser degree) has been the paradigm shifting successes of the field of ST. Systems theorists and thinkers such as Prigogine, Weiner, Bertalanffy, Bateson, and Forrester, have had an influential effect on many disciplines. In some cases producing impressive results, in other cases causing a field or entire discipline to shift its focus and paradigms to embrace new ways of seeing. But few have had the impact of one of the field's populizers, Peter Senge. Mostly borrowing Forrester's work in System Dynamics, Senge was at the right time and place with a well-calibrated message and set a forest ablaze with Systems Thinking. Senge did what others had attempted to do for nearly one-hundred years in a very short time. He made Systems Thinking popular. Since then there have been many more contributions to the field, in particular from researchers at the Santa Fe Institute (SFI) who have turned science on its head with a new brand of systems thinking that embraces an interdisciplinary approach to science that combines holism and reductionism, quantitative and qualitative analyses, and a systemic lens.

It is important to recognize the two forces that transform academic fields: (1) the natural forces that cause Discipline X to transform itself into Systems X; and (2) the success and subsequent popularization of ideas that influences what people adopt as Systems Thinking once they start searching to identify what it is. This is important because, often, that which is publicly available is not always the current best practice. To use a textbook analogy, the science that is in textbooks is often 20-30 years behind the science that is current.

In the past 70 years, Systems Thinking has had several transformations. Scholars use the metaphor of "waves" (See Figure 4) to describe the major transitions it has made.

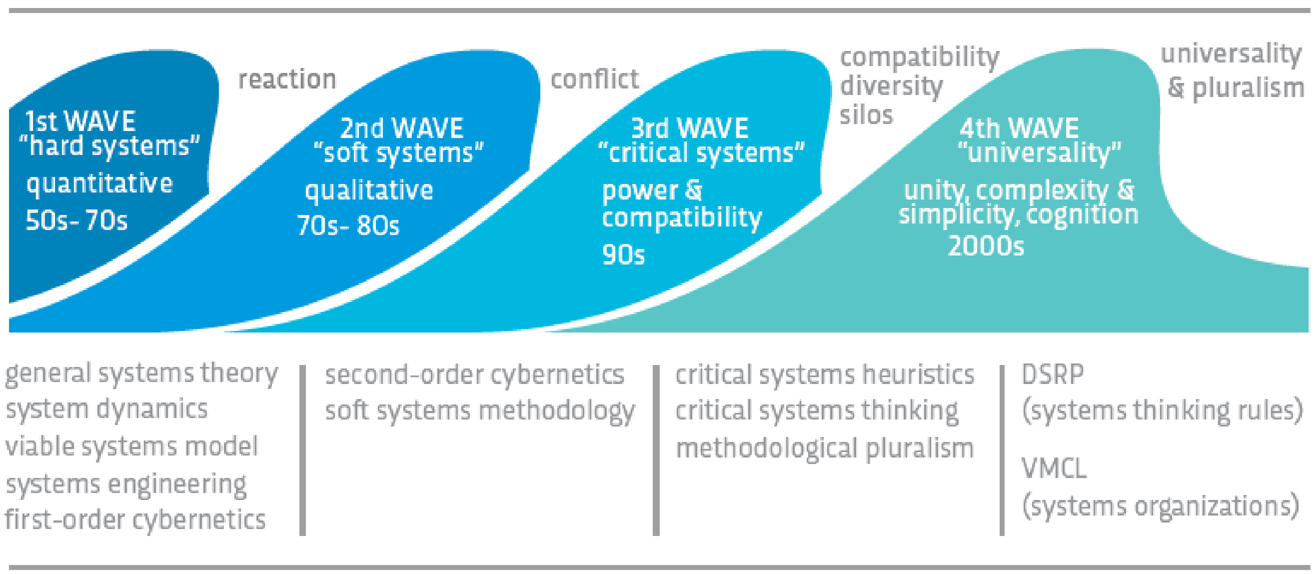

Fig. 4. The Systems Thinking Waves. The diagram depicts the waves and a sample of associated methods, theories, and approaches

A summary of a vast literature is often difficult, if not inadvisable. Even more so for something like systems thinking, that is of interest to both scientists and academics as well as practitioners and the general public. For this reason, we have tried to summarize the literature in a way that is accessible and maintains fidelity to what the literature says. If for nothing else but pedagogical purposes, summaries are useful. A summary of the interdisciplinary literature (4, 5) relating to systems thinking points to the following conclusions:

1. There is a universality of certain structures (DSRP). Namely,

Patterns	**Elements**		
Distinctions (D)	identity (i)	$\leftrightarrow$	other (o)
Systems (S)	part (p)	$\leftrightarrow$	whole (w)
Relationships (R)	action (a)	$\leftrightarrow$	reaction (r)
Perspectives (P)	point (ρ)	$\leftrightarrow$	view (v)

2. These DSRP structures exist in both mind (cognition) and nature (a.k.a., reality).

3. Awareness of these structures (a.k.a., metacognition) makes a significant difference in all walks of life and success in all domains.

4. Systems thinking is an emergent property of DSRP simple rules.

It is increasingly clear that the D, S, R, and P structures identified in number 1 above cannot be separated from each other. In other words, they exist in a constant and dynamic interplay. In addition, each of the D, S, R, and P structures is necessary and sufficient for each of the individual structures to exist. This means that, in order for an S (part-whole system) to be formed, Ds (distinctions) need to be made, Rs (relationships) need to exist, and Ps (perspectives) need to be taken; and vice versa. Importantly, any given D, S, R, and P structure cannot be divorced from its two elements nor can the elements be divorced from each other. For example, we are near-constantly making *identity* distinctions (D^i) and often unaware of the *other* distinctions (D_o) we are implying when doing so. Nevertheless, the *other* exists when we articulate an *identity*.

That these structures exist in mind and nature (number 2 above) is perhaps read as a philosophical statement, but it is based on empirical findings. It does not mean that every DSRP structure that we build in our minds exists in nature or vice versa. But it does mean that the D, S, R, and P structures are found in both realms. This is important because it reveals something about the goal of systems thinking. This paper posits that the goal of systems thinking is to increase the probability that our mental models are in alignment with reality. Working with a set of structures that is common to both mind and nature–akin to finding the same denominator to add fractions—is an essential first step in increasing the alignment of *what we think* with *how things are*.

Regarding number 3 above: it can be said that it is the *awareness* of these structures that constitutes the skill of systems thinking. Cognition occurs, whether you like it or not, often in ways in which we are unaware. Metacognition (awareness of D, S, R, P structures and dynamics) helps us to see structurally what we are potentially missing and fill in the gaps of our

Table 4. ST Ideas Past and Present

ST in the Past	ST in the Present
Systems thinking is EITHER: 1. a specific stepwise process or model as in soft systems methodology or system dynamics, 2. a list of systems science ideas to remember as in the "habits of systems thinking," or 3. a general statement of holism as in "systems thinking is holistic thinking."	Systems Thinking is: • Systems thinking is not something you can *do*, but something you *get* from doing simple rules. • Systems Thinking is an emergent property of mixing and matching four combinatorial rules (DSRP). • It is a process of structuring Information ($\mathbb{I}$) by thinking ($\mathbb{T}$) which includes making distinctions (D), organizing systems (S), articulating relationships (R), and taking many perspectives (P). • This process yields new distinctions, systems, relationships and perspectives, the sum total of which are a mental model ($\mathbb{M}$). • The mental model is clearly distinguished as an approximation of reality ($\mathbb{R}$) and is tested against reality in order to take in more Information

knowledge. Notably, one's one awareness of how ideas are constructed allows for the corollary teaching and development of the same skills in others.

The idea that systems thinking is an emergent property (number 4 above) is a significant shift in pragmatic terms. It means that if one wants to "do systems thinking" or "get better at (developing the skill of) systems thinking" one must recognize that systems thinking itself is an emergent property of a process. It is not something you can "do" per se, but rather something you "get" as a result of employing the DSRP patterns. Although "doing DSRP" does not require metacognition (it is hypothetically possible for a person to be good at doing DSRP without knowing it), being aware of the DSRP structures (metacognition) significantly increases the probability of one becoming a systems thinker.

There is a tremendous amount more written about Systems Thinking v4.0 and DSRP (4–7) as well as numerous resources including textbooks, syllabi, and slide decks for teaching it[‡]. Here we have provided a brief summary. For the SX or SE program leader, it is important to understand the specific differences between the ST of current and the ST of past.

4. How systems thinking (v4.0) is different from the systems thinking of the past.

We will give you the punchline at the outset. Table 4 outlines the basic difference between ST in the past and present:

There have been many developments in the field of systems thinking over the past 70 years. At its core, systems thinking is a cognitive science. So, this change has been accelerated over the past 20 with the advent of modern neuroscience and cognitive science. Let's take a look at how it has changed in order to assess how Systems Engineering departments, in particular (but all Systems X departments in general) may need to adjust to new insights from the field of systems thinking.

Many SE departments are asking themselves, "What does the future of SE look like?" And most will concur that SE is a portmanteau of systems thinking (as foundational) and Engineering. But, it matters what flavor of ST they are utilizing. Indeed—given the foundational nature of ST to SE—there is some irony involved when SE departments ask what the *future* of SE looks like while using a significantly dated ST model from the *past*—which many, unbeknownst to them, are doing. In this sense, the future of SE looks a lot like engineering in the systems-thinking-*present*. In other words, the *present* state of ST is far ahead of the many concerns and problems faced by modern SE departments; it is, in one sense, the future of SE. This is not by accident or because systems thinking is somehow "better" than SE. It is because the field of systems thinking is working on problems related to systems thinking. Let me give you an example—a generalizable vignette:

Bertalanffy was influential in the 1950s when he published General Systems Theory or GST. One of his main influences (even to people who don't know they were influenced by him) was to fight against what he termed, *reductio ad absurdum* or "reduction to absurdity," or simply absurd reductionism. He posited that "systems thinking was about holism, not reductionism." This became a popular refrain and today it has been adopted by many. For example, an excellent SE text used in SE departments states that, "ST is a holistic mental framework and view that recognizes a system as a whole entity first. . . " The primacy of holism is one of the field of systems thinking's most "popular and profitable products." Scores of people reference it and use it. And, it is probably wise to count that idea as a success and allow its popularity to continue. But for people who study systems thinking, these ideas have a long lasting effect. We research what people do, cognitively and behaviorally, with such mental models. This mental model (pro holism) had both its benefits, and its negatives. This pro-holism model liberates thinking, but it also *constrains* it. Where it may release biases, it also creates some. And so, systems thinking as a field moves on to newer and more reliable, valid, and tested ideas. *But—and here's the important part—as the systems thinking field moves on,*

[‡] https://help.cabreraresearch.org/getting-started-for-higher-education

other fields, focused on the difficult problems they face within their fields, aren't always following along. They don't update their mental model based on the hard-won wisdom and insight offered by the systems thinking field. And so, they begin to be outdated.

For example, we now know that holism without reductionism and vice versa are illogical and impossible. That the choice between them is a false choice—a false dichotomy—something akin to the debates that occurred in human development around nature *versus* nurture. After many years, battle bruised adversaries had to admit that both were interdependent and mutually important. We know that there have always been tendencies in science toward two archetypes: "*splitters*" and "*lumpers*" or reductionism and holism. Some hone their craft of reductionistic splitting while others hone their holistic lumping. But, we also know that future 21st Century skills require a new kind of person with an amphibious kind of skill set: the *splumper*. The Splumper is a person who readily does both. Who neither focuses more on the part nor the whole but on inseparable interaction between part-and-whole. Nobel Laureate Murray Gell-Mann said it this way at the founding of the Santa Fe Institute (SFI), one of the premier systems science institutes: We all know that in most situations, theory has to advance along two tracks: the fundamental search for dynamical explanations on the one hand, and on the other, the phenomenological search for pattern in the laws of Nature. There are associated experimental domains in each case...There is always a reductionist bridge between these two kinds of explanation, the fundamental and the phenomenological. (I assume all of us are in principle reductionists.) But it often takes a very long time to construct such a bridge, such as the one between the brain and the mind, even though great strides are being made. While the construction is going on, it is necessary to pursue both approaches, which means in this case to study both the brain and the mind. There are some psychologists and pop psychologists who like to place people on a scale running from Appolonian to Dionysian, where, roughly speaking, Appolonians tend to favor logic, rationality, and analysis, while Dionysians go in more for intuition, feeling, and synthesis. In the middle are those tortured souls, the Odysseans, who strive for the union of both styles. The new institute would have to recruit a number of Odysseans to be successful!(8) This may appear at first glance to be philosophical or abstract to make a practical difference to everyday SE applications. Let me assure you it does. It is a common complaint among SE experts that in real-world contexts SE'ers are eschewed by other Engineers for a particularly frustrating behavior; a behavior that is born of "holism first training." The situation plays out something like this:

> A bunch of "regular engineers" analyze a particular problem, P, and conclude certain things about it. The systems engineer in the group says, "But, you need to look at the system that P is a part of!" To which the regular engineers roll their eyes, contemplating all the extra work and scope-creep involved and weigh that against the agility and speed needed to keep up with the pace of innovation.

This somewhat satirized tendency is all too real. And, it is a behavior that is the direct result of "holism first training." If Systems Engineers are to drive innovation, they must be at the forefront of innovation, driving the pace and agility needed to compete. SE cannot require months of problem definition followed by months of scope-creep. Developing deep skills in Systems Thinking where SEs become agile and fluid in their use of DSRP patterns means that they can not only avoid hindering and not only "just keep up," but drive the pace of innovation while simultaneously considering more variables. In addition, there is reason to believe that that innovation based on purely reductivist methods will slow down, if it hasn't already. Without the corresponding knowledge about what happens when stuff gets lumped back together, reductivist innovation ends up plagued by unexpected emergent features. The emergence of the field of interaction design is a good example of this fact. Unfortunately, this occurs often, and even worse, there are plenty of non-systemic explanatory frameworks for why it occurred. The most pernicious and pervasive—at least among many XEs, computer scientists, and technologists—refuses to see social contexts and systems as anything other than external to (and distinct from) technology. As a result, problematic system behaviors are often categorized as "user error."

The empirical debate between part-whole is merely one example of the kinds of things systems thinkers give a lot of thought, time, and attention. Boundary distinctions is another. For example, in the 1970s, and even before, it was thought to be critically important to pay attention to the *system's boundary* (note that this is *singular*). For example, a common SE-style description of this idea is, "Distinguishes the system from its environment.(9)" Today, you'd be hard pressed to find an SE department that didn't provide some coverage on the issue of navigating the system boundary to determine what is inside and what is outside the system. Of course, this remains an important idea today and every systems engineer should be aware of the various biases and considerations that go into establishing a system boundary either as a mental model or recognizing an actual system boundary in reality. Boundary problems are very much an issue in SE. Writ large, SE programs focus on spatial boundaries. But there are also social, institutional, temporal, scale, causal, economic, etc. boundaries, and these are never encountered individually (and, because they're fractal in nature, never just at one level of scale). Often these boundaries extend across scale, and are not so distinct as the list implies. This alone explains many modern engineering failures. That said, Systems thinking as a field focuses a lot of time, resources and attention on this issue of boundaries. We know much more today about how these boundaries are navigated cognitively. And, one of the things we know is that it's not just one *singular* system boundary. It is actually a *fractal* set of boundaries. Boundary distinctions are occurring at every level of scale in the real-world and in our mental models. Again, the systems thinking present is well-aware of this fact. But many SE and other SX departments continue to peddle older versions in need of an upgrade.

One of the central merits of DSRP (Systems Thinking v4.0) is that it captures both holistic and reductive approaches, showing that the difference between the two is really the direction of inquiry, the ontology that inquiry assumes, and what sort of claims can be regarded as legitimate within that framework. DSRP recognizes and expresses the genuine plurality of approaches as being composed of the same basic structural components, while also offering those structural components in a way that expands the field of possible inquiry. DSRP is an *aufhebung* in the Hegelian sense: simultaneously preserving, changing, advancing, and overcoming the dichotomy it sublates. Rigid dualities, while perhaps not quite illusory, are oversimplifications. This is the epistemic import of DSRP as a theory. The ontological import of DSRP is as follows: it is primitivistic about structure, holding that structure is part of the "regular furniture of the universe." This is important, since the primitivism would be unnecessary if structure were in some sense dependent on humans, human cognition, etc. To illustrate this, consider the alternative view: that structure is something that, in some way or other, we bring to the universe. On such a view, what distinguishes the set of atoms from the set of atom-or-dolphins is that we humans have a simple term for the former set, or we find it psychologically more natural to think in terms of 'atom', or whatever. This view would not say that the set of atoms is a more structurally fundamental representation of the universe than the set of atoms-or-dolphins. For DSRP—which is both primitivistic and realistic about structure—this sort of view is nonsense, because if structure were just a reflection of our language, or our cognitive predilections, or whatever, then so too would be scientific facts, laws of nature, and so on. The result is an unpalatable view of reality that is woefully dismissive of actual problems faced by actual scientists and everyday people. The point of human inquiry, as philosopher Theodore Sider(10) put it, is to conform itself to reality; the world is "out there" in the robust sense of the term, and it's on us to comprehend it as best we can. In other words, the best mental model is the one that best "carves nature at the joints", and the only way to do that is to be a realist about structure.

These are just a few specific examples—identity-other boundary distinctions, part-whole systems, holism-reductionism, and epistemological-ontological —but the implications of these and other discoveries must lead us to develop better models that reconcile these inconsistencies. These models are best represented by the various versions of systems thinking that have occurred historically as "waves." The truth is, most of today's SE departments exist predominantly in the first wave (STv1.0). A few have evolved into the second wave (STv2.0). Very few have evolved their programs writ large to the fourth wave (STv4.0). There are many many more examples like the few discussed above. Table 5 compares and contrasts a few of the more salient among them.

The ST field for example, has focused not only on the theoretical developments in ST, but also on pedagogical, developmental, and cognitive aspects of ST(16–20). We know far more about not only the underlying cognitive rules of systems thinking but also, for example: the kinds of biases students default to; where they struggle to learn certain constructs; the concepts that are most important for developing a deep understanding and abiding practice; and what types of activities can be used to unlearn ingrained habits of thinking. For example, we know that:

- identity-other distinction making, is far more difficult for students to gain deep skill using than part-whole thinking (which they get exposed to K-12);
- students have an easier time taking perspectives from identities that "have eyes" (e.g., humans, stakeholders, frogs, the enemy, and other animate, human-like things) than from things that don't (e.g., abstract concepts like economics, chair, wallet, etc.) which is critically important for SE students who are often asked to take abstract-conceptual-perspectives on every project (such as: Economic, Technological, Historical, Social, Health Safety, Political, Emotional, Moral/Ethical, Security, Ecological, Cultural, Legal, Organizational, and Economic);
- students have little difficulty with step-wise lists and processes but have great difficulty implementing nonlinear, combinatorial set of rules (the latter is fundamentally a systems thinking skill and makes a form of adaptive thinking possible);
- students have an easier time grasping composite "molecular" or "jig" structures as a gateway to understanding the value of "atomic" structures like DSRP.

5. Conclusion

As SE programs (and other SX programs) consider the future of what their discipline, and training in their discipline, looks like, they inevitably discover that the "capitalized SE" (or SX) is really a "lowercase se." This means that although SE is formalized as a discipline, a department, a degree, or a job title—all proper and capitalized nouns—it is also a real-world function. In other words, "se" needs to be done regardless of whether the job title calls for it—the systems engineers deal with, de facto, require a systems view. This fact makes distinguishing SE (or se) from XE even more critically important— because it means that the skills that truly differentiate an SE from an XE are necessary across the engineering fields. Those skills, predominantly, are borne of the ST part of SE. Systems Engineering (capitalized) and systems engineering (lower case) need to update their systems thinking to version 4.0.

I leave you with two stories, both of which come from one of the top Systems Engineering departments in the world. The first story is from the faculty:

> Laura and I sat with two leaders of the SE Department who wanted to build into their departments Systems Thinking v4.0. They shared with us the problems they were seeing which summarized were that although their graduates were exposed to numerous tools and techniques, methods, and models over their four years, many of them failed to use these tools in a *systemic way.* "It is as if," these leaders said, "we gave them a wood shop with every conceivable tool and taught them how to use those tools, but forgot to develop in them *carpentry skills*." These leaders were right. Even *systemic tools*, put into a *non-systems thinkers' hands* will be applied in *non-systemic ways.* In fact, the reverse

Table 5. ST Ideas Past and Present

Basic concept	Current SE Treatment	ST v4.0 (2020) Treatment
Basic Skills of ST	Id elements of system; understand connections among elements; how elements interact to achieve system purpose; understand system relative to other systems	...Information ($\mathbb{I}$) is structured by thinking ($\mathbb{T}$) which includes making distinctions (D), organizing systems (S), articulating relationships (R), and taking many perspectives (P). This process yields new distinctions, systems, relationships and perspectives, the sum total of which are a mental model ($\mathbb{M}$). The mental model is clearly distinguished as an approximation of reality ($\mathbb{R}$) and is tested against reality in order to take in more Information ($\mathbb{I}$). . . (ST cycle continues)
Perceived Benefits of ST to SE	Holistic view makes SE valuable contributor to IDS efforts	And/Both view of parts-wholes leads to fractal understanding and algorithm; also, importantly inheres the same And/Both view of identity-other Distinctions, action-reaction Relationships, and point-view Perspectives. In other words, focusing on the whole in part-whole Systems (S) is an equivalent bias to focusing on the other in identity-other Distinctions, focusing on the reaction in action-reaction Relationships, or focusing on the view in point-view Perspective. Not only is it nonsensical, it preselects what to see and not see. That is, A DSRP approach provides not just 2-dimensions of ST, but 8.
	Enables systems to be identified, classified and represented to lead to deeper understanding of inner workings and interconnections of relationships that lead to system-level behavior	Increases probability of "getting it right" by increasing the probability of alignment based on common structural traits across mind (epistemological) and nature (ontological). Provides the simple rules that can be followed (somewhat robotically but also adaptively) in order to bring about systemic thought.
	Allows one to establish boundary of system, and scope the systems decision process	Completely changes the mental representation of boundaries as being singular to being many and fractal/self-similar across scale.
	Defines the interconnected relationships among system elements	Defines the perspectives that frame boundaries, organization, and relatedness of the parts of the system and how those differ with shifts in perspective.
Definition of ST	"Systems thinking is a holistic mental framework and view that recognizes a system as a whole entity first, as a whole, with its fit and relationship with its environment being primary concerns(9)"	Systems thinking is not something you can do, but something you get from doing simple rules. Systems Thinking is an emergent property of mixing and matching four DSRP rules.(7)
The definition of boundaries has expanded	Boundaries: "Distinguishes the system from its environment.(9)" Defined as a singular system boundary.	Boundary-distinctions (Dio) are fractal and self-similar across scale and occur at every element yielding far more complexity both on the mental model side (bias awareness) and on the reality/nature side (real-world interfaces)(5).
Whether systems have purposes or not	System defined as "An integrated set of elements that accomplish a defined objective.(9)"	This can be viewed two ways. Either all systems have a POSIWID (purpose of a system is what it does) purpose or the definition of a system need not include purpose. Either way, *purpose* is sort of unnecessary or ill defined as an objective reality that can be known other than retrospectively. In other words, in the definition at left, *who* is doing the defining?
Are systems really open and closed?	Open: Can interact with the environment Closed: does not interact with environment ; do not occur in nature(9)	In many ways all systems are open; so this is a matter of perspective; a trick used to solve problems or to account for a degree of variance that is irrelevant from the perspectival frame. Ergo, the perspective rule establishes whether the system can be considered "open" or "closed" for analytical purposes.
Is everything interconnected?	Yes.	No. This is a popular but incorrect trope of systems thinking. Everything is not interconnected. Everything is indirectly interconnected, eventually. But, the pattern of non-connection is as important as the pattern of interconnection.
Is ST exclusively holistic?	Yes. ST favors holism.	No. Another common but incorrect trope. ST is both holistic and reductionist with no favor to either.
Is feedback universal?	Yes.	No. Important yes. But feedback in 2020 is two things, first, a necessary part of the ST Loop; second, simply an R or set of Rs that exist or not in mind and nature. Not *all* systems have feedback, but most of the ones that are interesting to us do.
The in between	It's all about interconnections and interfaces and integrations	Well, technically it's not all about them but they are incredibly important "engines for innovation." ST v4.0 provides an algorithm called RDS that quantifies what happens universally, both structurally and dynamically, at these interfaces.(11–13)
Role of tools, modeling, applications	Need more of them!	Agreed. No SE should make it through a program without being able to actually create a systems model of something. However, teaching SE'ers all the tools in the world will make them tool owners but it won't make them carpenters. ST skills are the foundation for using these tools in a systemic way.
The importance of the System of systems (or internet of things)	Sees as important.	Sees as important but also demonstrates precisely what is meant by it. Navigating the internet of things without DSRP is navigating it with a blindfold on. DSRP details the structural and dynamical possibilities of such networks.
Importance of design thinking (DT)/agile?	Important in some applications.	Agreed. DT is increasingly popular but DT without the ST Loop and DSRP has few teeth. The "devil in design thinking"—operationalizing the steps—is in the details of DSRP. The ST loop is the basis for design thinking (incrementalism)(14, 15).

> is also true, a *non-systemic tool*, put into a *systems thinkers' hands* will be applied in *systemic ways*. The carpentry metaphor is a powerful and analogously accurate one.

The second vignette is from students:

> Laura and I were asked to facilitate a session with all the graduating seniors in the SE program with no faculty present so that they could speak freely and candidly. It was a long and lively session where these soon-to-be-minted SE's shared their 4 years of experiences. Their answers to one question particularly stood out to me. We asked them, "How would you change the degree curriculum?" There was a lot of discussion and near-total agreement, but all of it centered around the words of one senior who said, "There should be more opportunities or projects where we get to work on teams with other types of engineers because this is where we systems engineers shine. See..." he continued, "systems engineers and this degree has a bit of a runt-of-the-litter status among the other engineering degrees. We get made fun of as not being as serious or as technical. But, when we get to work with students from *other* engineering disciplines on teams doing real projects, we end up running the show and it becomes obvious who the Alpha is." The room exploded with applause. Every one of these seniors felt this way. They had something to prove, yes. But they also *begged* for the chance to prove it. That's the level of confidence they had in their skills. They wanted more opportunities to let their skills do the talking for them and *show* the value of systems engineering rather than *tell* it.

We think that these two stories capture the systems in systems engineering well. They also speak to the T-model of breadth and depth that makes systems engineers unique. Distinguishing the future of SE from XE and updating to ST version4.0 can call in a dynamic and promising future for SE programs and these programs serve as a model for all Systems X. Although it may seem too fine grained to be of global importance, the idea that a Systems X program requires 3.5 units of systems thinking and 3.5 units of X means that the program needs to be truly integrated and balanced.

References.

1. H Gibson, Ph.D. thesis (Harvard University Business School) (2015).
2. H Gibson, S Gillespie, P Evangelista, M Dabkowski, Systems engineering in *Routledge Handbook of Systems Thinking*, ed. Derek Cabrera, Laura Cabrera, and Gerald Midgley. (Routledge), (2021).
3. Gibson, Hise and Morales, Ricardo and Schreiner, James, Engineering leadership in *Routledge Handbook of Systems Thinking*, ed. Derek Cabrera, Laura Cabrera, and Gerald Midgley. (Routledge), (2021).
4. D Cabrera, L Cabrera, E Cabrera, A literature review of the universal patterns and atomic elements of complex cognition. (2020).
5. DA Cabrera, Ph.D. thesis (Cornell University) (2006).
6. D Cabrera, L Cabrera, Distinctions, systems, relationships, and perspectives dsrp: a theory of thinking and of things. *Eval Program Plann* **31**, 311–317 (2008).
7. L Cabrera, D Cabrera, *Systems Thinking Made Simple: New Hope for Solving Wicked Problems.* (Odyssean Press, Ithaca, NY), (2015).
8. M Gell-Mann, The concept of the institute in *Emerging Synthesis in Science*, ed. D Pines. (Addison-Wesley, Reading, MA), pp. 1–15 (1988).
9. GS Parnell, PJ Driscoll, DL Henderson, *Decision Making in Systems Engineering and Management.* (John Wiley & Sons), (2011).
10. T Sider, *Writing the Book of the World.* (Oxford University Press), (2011).
11. Cabrera, Derek, Jig: Barbell (https://blog.cabreraresearch.org/jig-barbell) (2020) Accessed: 2020-4-5.
12. D Cabrera, Relationships (r) are not enough! (https://blog.cabreraresearch.org/relationships-r-are-not-enough) (2020) Accessed: 2015-8-18.
13. Powers, Erin and Cabrera, Laura, GasMarts, umbilical cords, and eco bridges: Deconstructing relationships to understand complex systems (2015).
14. D Cabrera, Dealing with the devil in design thinking (https://blog.cabreraresearch.org/designthinking) (2020) Accessed: 2016-2-25.
15. D Cabrera, Solving the dilemma of design thinking (https://blog.cabreraresearch.org/solving-the-dilemma-of-design-thinking) (2020) Accessed: 2014-7-22.
16. D Cabrera, L.; Cabrera, Learning systems thinking at the graduate level: A case study in applying systems thinking to public policy. *Cornell Policy Rev.* **Special Issue** (2016).
17. D Cabrera, L Cabrera, What is systems thinking? in *Learning, Design, and Technology: An International Compendium of Theory, Research, Practice, and Policy*, eds. MJ Spector, BB Lockee, MD Childress. (Springer International Publishing, Cham), pp. 1–28 (2019).
18. D Cabrera, L Cabrera, Complexity and systems thinking models in education: Applications for leaders in *Learning, Design, and Technology: An International Compendium of Theory, Research, Practice, and Policy*, eds. MJ Spector, BB Lockee, MD Childress. (Springer International Publishing, Cham), pp. 1–29 (2019).
19. DA Cabrera, B Milstein, RS Gallagher, SJ Leischow, Practical challenges of systems thinking and modeling in public health. *Am. J. Public Heal.* **96** (2006).
20. D Cabrera, L Cabrera, E Powers, A unifying theory of systems thinking with psychosocial applications. *Syst. Res. Behav. Sci.* **32** (2015).