

When Systems Thinking Is Not a Natural Act

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Abstract—Competence in systems thinking is implicitly assumed among the population of engineers and managers – in fact, most technical people will self-identify as systems thinkers. But systems thinking competencies are not as prevalent as these assertions might lead one to assume. Controlled experiments show that systems thinking performance, even among highly educated people, is poor. This paper provides a set of systems thinking competencies and demonstrates how these are not as common as advertised. We also discuss how these competencies can be measured. Our main thesis is that systems thinking is not a natural act because evolution has favored mechanisms tuned to dealing with immediate surface features of problems. We discuss the implications of this philosophy and provide recommendations for closing the gap between the demand and supply of systems thinking.

Keywords - *systems thinking; systems engineering competencies.*

I. INTRODUCTION

The systems approach advocates a holistic approach aimed at identifying the emergent properties and non-linear behavior of systems. Ackoff [1] claimed that “you never learn by doing something right because you already know how to do it. You only learn from making mistakes and correcting them.” This philosophy has helped advance the management of complex systems through discovery, adaptation, innovation, stakeholder engagement, and problem reframing that have contributed to many successes in companies, schools, government, etc. Despite demonstrated benefits, failures to apply systems thinking have been credited for phenomenal system failures [2].

Extensive evidence points to the goodness and desirability of systems thinking which has led to its widespread adoption. Organizations provide systems thinking training and encourage their employees to apply systems thinking as a problem solving approach. However, organizations overlook two important considerations. The first is whether systems thinking is a natural act. That is, are systems thinkers born or made? This has important implications that can lead to overestimating an organization’s ability to develop and leverage systems thinking. The second consideration is when systems thinking should and should not be applied. We explore the interaction between systems thinking competencies, their measurement, application and observed effects, as illustrated in Fig. 1. We also focus on the enablers and barriers to improving systems thinking.

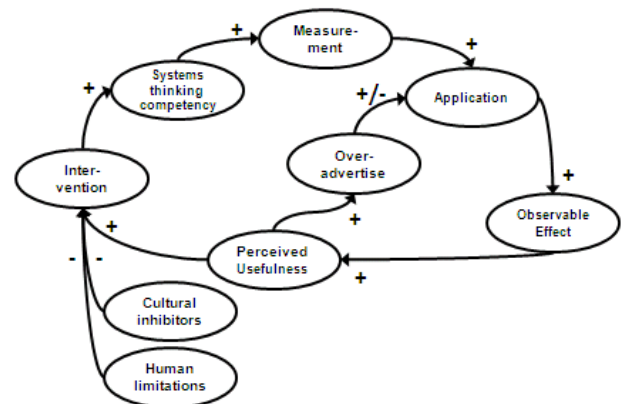


Figure 1. System dynamics view of systems thinking.

II. FOUNDATIONS OF SYSTEMS THINKING

A. The Face Validity of the Systems Thinking Construct

The number of frameworks and ideas surrounding the construct of systems thinking can be overwhelming. Consider the four foundations of systems methodology (holistic thinking, operational thinking, systems theories and interactive design) [3], five learning disciplines (personal mastery, mental models, shared vision, team learning and systems thinking) [4], thirty systems thinking laws (synergy, gradual process, life-cycle thinking, solution exploration, etc.) [5] and seven critical skills of systems thinking (dynamic, closed-loop, generic, structural, operational, continuum and scientific) [6].

These concepts have a high degree of face validity because on the surface they appear to be simply implementable components of the systems thinking construct. However, very little has been done to explain which competencies exist within a certain sample population and which competencies are appropriate for certain classes of problems. Despite the lack of understanding, organizations jump on the systems thinking band wagon hoping that it will improve performance. To appreciate the diversity of the systems thinking construct we explore a variety of perspectives – also referred to as competencies – that begin to bound this phenomenon.

B. Systems Thinking Competencies

In order to understand the systems thinking construct it is necessary to identify the competencies that are assumed in the various definitions. The following definitions stem from the engineering, management and social science literature. Each is synthesized into a specific competency

Systems thinking is a process of identifying, estimating or inferring how local policies, actions, or changes influences the state of the neighboring universe [7].

Competency: Ability to define the “universe” appropriately.

Systems thinking is also an approach to problem framing and solving, as viewing "problems" as parts of an overall system, rather than reacting to surface outcomes or events and potentially contributing to further development of the undesired issue or problem [8].

Competency: Ability to define the overall system appropriately.

Systems thinking is a framework that is based on the belief that the component parts of a system can best be understood in the context of relationships with each other and with other systems, rather than in isolation. The only way to fully understand why a problem or element occurs and persists is to understand the part in relation to the whole [9]. This includes the ability to envision and analyze higher-order consequences, so that they do not end up being unintended consequences.

Competency: Ability to see relationships.

Standing in contrast to Descartes's scientific reductionism and philosophical analysis, systems thinking proposes to view systems in a holistic manner [4].

Competency: Ability to see things holistically.

Consistent with systems philosophy, systems thinking concerns an understanding of a system by examining the linkages and interactions between the elements that compose the entirety of the system. Systems thinking attempts to illustrate that events are separated by distance and time and that small catalytic events can cause large changes in complex systems.

Competency: Ability to understand complexity.

Acknowledging that an improvement in one area of a system can adversely affect another area of the system, systems thinking promotes organizational communication at all levels in order to avoid the silo effect.

Competency: Ability to communicate across disciplines.

Systems thinking techniques may be used to study any kind of system — natural, scientific, engineered, organizational, human, or conceptual.

Competency: Ability to take advantage of a broad range of concepts, principles, models, methods and tools.

This is not an exhaustive list of competencies but rather it is intended to illustrate the specific competencies that are

embedded in each definition. A study of NASA engineers [10] validates these competencies as critical skills for complex systems. Thus, the initial set of systems thinking competencies include:

1. Ability to define the “universe” appropriately – the system operates in this universe
2. Ability to define the overall system appropriately – defining the right boundaries
3. Ability to see relationships – within the system and between the system and universe
4. Ability to see things holistically – within and across relationships
5. Ability to understand complexity – how relationships yield uncertain, dynamic, nonlinear states and situations
6. Ability to communicate across disciplines – to bring multiple perspectives to bear
7. Ability to take advantage of a broad range of concepts, principles, models, methods and tools – because any one view is inevitably wrong

This is not an exhaustive list but provides a summary of the commonly identified behavioral competencies across domains. Additional studies provide a similar set of competencies that described the cognitive characteristics, capabilities and individual traits of successful systems professionals [10; 11; 12]. There are some important limitations to these competencies that should be evaluated in light of their applicability.

C. Limitations of Systems Thinking Competencies

Despite these definitions and competencies, there is little consensus and major questions about: when is systems thinking appropriate? Does an individual need to possess all of the competencies to be considered a systems thinker? How many systems thinkers are needed in certain organizations? What are the contextual factors that affect the ability of systems thinking to be effective? Can systems thinking happen at many levels?

There is also the subtle but important difference between thinking abstractly about systems and taking action on these thoughts. For example, in suicide studies researchers make an important distinction between suicidal ideation (the thought of suicide) and suicide attempts [13]. The same distinction exists in systems thinking; scoring high in certain competencies does not necessarily lead to action. Furthermore, action does not necessarily lead to changes in behavior or observable effects as shown in Fig. 2.

A key step in understanding the manifestation of systems thinking involves the measurement of the construct, as discussed in the next section.

III. OPERATIONALIZING SYSTEMS THINKING

A. Measures of Systems Thinking

A variety of studies shed light on characteristics of engineers with high capacity for systems thinking. Toshima developed and standardized an aptitude test for systems engineers, which assessed systems thinking as a function of personality type [14]. Doyle, Radzicki, and Trees [15] measured changes in mental models in a simulation game. Since the content and size of the subjects' mental models increased and feedback thinking increased in this example, it proved to be a reliable way to measure/test systems thinking. Sweeney and Sterman measured systems thinking through concepts such as feedback, time delays, stocks and flows [16]. Frank has been working to test the level of interest towards systems thinking in engineers based on their preferences between choices described in forty questions [17]. Yet another approach is to measure the extent of systems thinking as being proportional to the information (bits) processed in problem formulation, which can be estimated by the network of relationships explored and the probabilities of connections being relevant.

The challenge with measuring systems thinking is that there is no standard way of isolating the effects of the various interventions or detecting which competencies are being brought to bear on certain problems.

B. Systems Thinking as a Latent Construct

Latent variables, as opposed to observable variables, are variables that are not directly observed but are rather inferred from other variables that are observed and directly measured [18]. Systems thinking fits the definition of a latent construct because it is best observed through a range of behaviors and abilities, even though there is no consistent measure. Furthermore, systems thinking is a collection of multiple concepts – or as discussed earlier, made up of multiple competencies – which make its measurement more involved. This concept is illustrated in Fig. 2.

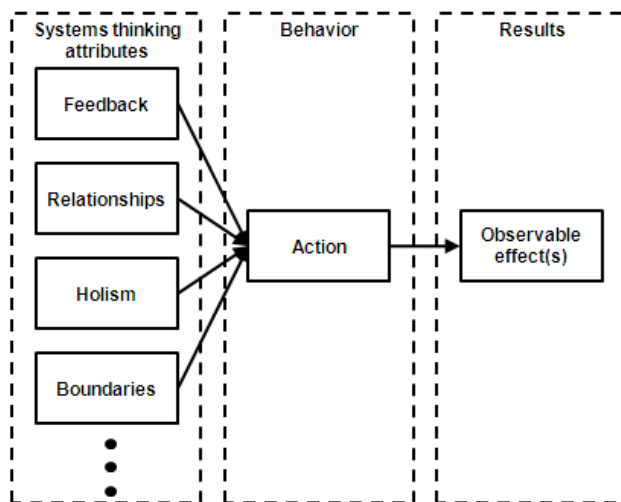


Figure 2. Relationship between systems thinking attributes, action and effects.

The diversity of properties of systems thinking make it difficult, but not impossible, to obtain empirical evidence that demonstrates its effect on decision making. The range of definitions also reduces measurement reliability since each researcher uses their own definition of systems thinking based on their domain of applicability. Despite these limitations there is ample evidence for systems thinking in organizations.

The best way to measure actions attributable to systems thinking may be to ask people to figure out why something went wrong or the source of a system failure. We conducted a long series of studies and developed several models of how people addressed such problems. This work is summarized in [19].

There is also a relationship between systems thinking and creative thinking. Previous studies showed that engineers judged to be creative tended to be 1) vociferous consumers of information from all disciplines and 2) able to see connections and distinctions that other people did not see [20].

IV. THE ACT OF SYSTEMS THINKING

We have identified systems thinking competencies and approaches to measuring them. Now we describe the cognitive act that we consider to be systems thinking and specifically focus on the question *when is systems thinking natural and when is it not?*

The first reason systems thinking is not a natural act is because human evolution has favored mechanisms tuned to dealing with immediate surface features of problems – Jared Diamond's book, *Collapse* [21], provides numerous examples of the downside of these “programmed” human tendencies and how they can lead to the downfall of societies. For example, the people on Easter Island did not realize that the root systems of the trees they were cutting down provided the means for capturing rainwater that enabled them to grow crops on an island with little if any soil. Once the trees were gone – all used up to roll statues from the quarries to the coast – they could not grow crops anymore and starved.

Catastrophic system failures such as the Mars missions also serve as evidence for the unnatural aspect of systems thinking. Dozens of spacecraft, including orbiters, landers, and rovers, have been sent to Mars by the Soviet Union, the United States, Europe, and Japan to study the planet's surface, climate, and geology. Roughly two-thirds of all spacecraft destined for Mars have failed in one manner or another before completing or even beginning their missions [22]. It is debatable whose failure it was (i.e., requirements, testing, organizational culture, individual mistakes, etc.) but the fact still exists that more mature systems thinking could have increased the probability of success.

The challenge with systems thinking is that emphasis is often placed on mechanistic/reductionist approach in decision making. Example phenomena and their features are listed in Table I [19]. These help illustrate the abilities,

limitations and approaches for overcoming shortfalls in systems thinking.

A second explanation for the lack of systems thinking is bounded rationality [23]: the complexity of the systems we are called upon to manage overwhelms our cognitive capabilities. Some complex systems are beyond human ability to comprehend, which lead to a natural reductionist reaction that works against the competencies discussed earlier. Other examples of human limitations that can lead to system failures are provided in Table I.

The next issue is whether systems thinking competencies can be created – or whether one must be born with them – and why these competencies, once developed, are often inhibited in the heat of the moment. In other words, when is Gladwell’s Blink [24] a best practice; and when is it not? In general, intuition works well in frequent and familiar situations; it often fails in situations that are infrequent and unfamiliar due to the strong tendency to map unfamiliar cues to familiar situations that subsequently prompts an inappropriate response.

TABLE I. PHENOMENA, QUESTIONS, ABILITIES, LIMITATIONS, AND APPROACHES TO SUPPORT [19]

Essential Phenomena	Human Abilities	Human Limitations	Enhancing/Overcoming
Estimation: How to assess what is happening or will happen?	Good at recognizing familiar patterns and mapping to action	Inaccurate mental models and perceptions of the state of the process	Stochastic forecasting models and displays of filtered, smoothed & predicted states
Stakeholders: How should stakeholders’ interests be balanced?	Good at specifying interests and importance of associated attributes	Difficult to deal with stakeholders’ differing and conflicting interests	Multi-stakeholder, multi-attribute models that enable tradeoffs and decisions
Future: How should future uncertainties be considered?	Good at imagining alternative futures and possible consequences	Difficult to consider future contingencies and specify long-term returns	Decision models that provide economic assessments of the value of contingencies
Challenges: How should management challenges be addressed?	Good at running the “as is” business to achieve familiar objectives	Tendency to be tactical rather than strategic & too focused to see situation	Toolkits that enable systematic addressing & pursuit of the essential challenges
Change: How should fundamental change be pursued?	Good at articulating a vision and leading people in pursuing this vision	Difficult to recognize forces for change and then commit to change	Methods that address value deficiencies, work processes, decisions & social networks

V. INHIBITORS TO SYSTEMS THINKING

Despite the broad applicability and benefits of applying systems thinking to situations there are a number of elements that inhibit their development and application.

The first is over-specialization. Workers with job functions that have a narrow focus or are based on highly specialized tasks are naturally inclined to have a limited view of the system. This makes it more difficult for them to step back and exercise the competencies referred to earlier.

The second inhibitor to systems thinking is having a short time horizon. Workers with a constrained view of the system do not have the incentive to apply systems thinking.

A third inhibitor is personality trait of individuals. One study showed that certain personality traits are correlated with performance levels of systems engineers [14].

A fourth inhibitor that can limit systems thinking is the set of institutional constraints in rigid, hierarchical organizations. Organizations that are required to follow strict command and control protocols, such as the military, or highly bureaucratic environments, such as the federal government, are not good candidates for systems thinking.

A fifth inhibitor can be a combination of factors such as cognitive complexity, internal locus of control, occupational level, educational level, and interest [25].

Another inhibitor is the educational system. From a young age, students ask insightful questions and are curious about why things happen. Elementary school curricula are too rigid because it is structured around finding the answer without exploring possibilities. This is also due to our teaching memorization rather than problem solving, in part because such tests are easier to grade.

Systems thinking capability can be seen as a part of a larger concept which includes systems skills, domain knowledge/experience, interpersonal skills/characteristics, and environment/ incentives as shown in Fig. 3.

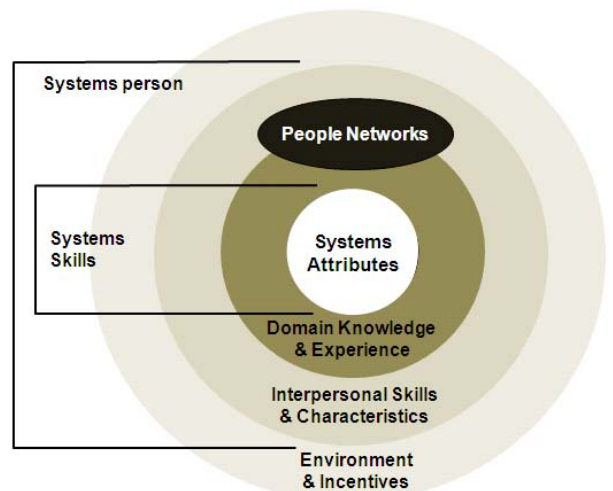


Figure 3. Systems person model (adapted from [26]).

VI. IMPLICATIONS

Considering the shortage of systems thinkers it is logical to explore ways in which more can be developed. Research shows that systems thinkers can be developed through experiential learning [12] and coaching [27]. Several examples of systems thinking interventions illustrate their ability to alter thinking, behavior and results as shown in Table II.

TABLE II. SYSTEMS THINKING INTERVENTIONS

Study	Sample population (n); Intervention (time)	Systems thinking measure(s)
Huz, et al. (1997) [28]	Mental health professionals in New York (n = 18); System dynamics model building by a group (t = 6 months)	(1) Participants' perceptions of the intervention, (2) Shifts in participants' goal structure, (3) Shifts in participants' change strategies, (4) Alignment of participant mental models, (5) Shifts in understanding how the system functions, (6) Shifts in network of agencies that support services integration, (7) Changes in system-wide policies and procedures, and (8) Changes in outcomes for clients.
Cavaleri & Sterman (1997) [29]	Insurance claims professionals (n = 70); Beer Game (t = not reported)	(1) changes in personal perceptions, (2) changes in behavior, and (3) competency in understanding the principles of the Beer Game
Sweeney & Sterman (2000) [16]	University students (n = 225); Bath tub and cash flow exercises (t = 2 weeks)	(1) feedback, (2) delays, and (3) stocks and flows.
Witjes, et al. (2006) [30]	7-10 year old children in rural Colombia (n = 22); construction of a rain water recollection system and organic vegetable garden (t = 5 months)	Interpretation of drawings in terms of three systems thinking levels: (1) systems, subsystems and synergy, (2) possessiveness and feedback, and (3) chaos and order.
Doyle, et al. (2008) [15]	University students (n = 46); Simulation of the economic long wave model (t = 2 weeks)	changes in (1) mental models and (2) feedback thinking

Systems thinking could also be developed via games or flight simulators as is done in other disciplines such as aviation and operant conditioning. The case method can also help, such as used at Harvard Business School and the Wharton School. In the end, we need more efficient and effective ways to develop systems thinkers in order to prevent some of the system failures that have resulted in financial, technical and societal losses.

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