Systems Thinking for Complex System Governance

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Abstract For effective implementation of Complex System Governance (CSG), a necessary condition is a high level of systems thinking capacity. Being able to ‘think in systems’ is essential if effective design, execution, and development are to be undertaken for CSG. An individual must be capable of understanding the complex system’s components and how they comprise the whole system. This chapter focuses on better understanding systems thinking in relation to CSG and establishing the level of systems thinking held by an individual/group. Three primary development objectives are pursued for this exploration. First, following an introduction to the chapter, systems thinking is examined. The focus is on providing a rigorous treatment of systems thinking. Second, the role of systems thinking in CSG is examined. This examination is targeted to examine how systems thinking is a fundamental and vital aspect of CSG. Third, a systems thinking instrument is introduced as a vehicle to establish the state of systems thinking of an individual/group. This instrument provides a ‘snapshot’ of both individual and aggregate systems thinking capacity. The chapter closes with implications that systems thinking holds for the emerging CSG field.

Keywords Complex systems governance · Systems thinking · Systems thinking capacity

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C. B. Keating et al. (eds.), *Complex System Governance*, Topics in Safety, Risk, Reliability and Quality 40, https://doi.org/10.1007/978-3-030-93852-9_14

1 Introduction

Systems thinking is touted as an important future capability for society and is frequently suggested as essential to prepare individuals to deal with increasingly complex systems [5]. At a fundamental level, complex systems have several defining characteristics, including:

1. *Large number of entities*—complex systems invariably have a large number of interconnected entities that exponentially increases the number of states the system can occupy and the number of interrelations between elements that are possible.
2. *Richly interrelated*—beyond just the large number of entities and interrelationships among them, complex systems interconnections are 'rich.' This suggests that there are large degrees of 'different' interconnections. These connections are dynamic in nature, with a degree of instability, difficult to completely grasp or understand, and lacking any precision that can provide a definitive description of the interconnection attributes.
3. *Dynamic shifts*—over time, a complex system is subject to change. These changes may follow from elaboration of interconnections or from adjustments in response to environmental change/shifts. Complex systems are not static and defy approaches that assume a 'static/stable' state for purposes of analysis.
4. *Emergence*—the structure, behavior, and performance of complex systems cannot be fully known, or calculated, in advance of the system being operated. The behavior/performance is not known until the system operates. This is where emergence, generated from the interactions among the elements, produces behavior or performance that cannot be known or predicted in advance.

The landscape and need for engaging in CSG has changed substantially as we move firmly into the twenty-first century. And with near certainty, the complex system attributes described above are not going to abate in the near future. In fact, we can posit that the conditions will be exacerbated by multiple confounding factors. Among these factors, we would include (Fig. 1): (1) information- and technology-driven aspects of systems continuing to proliferate as systems become more complex and technology driven, (2) increasing stakeholders who have a perceived interest in a complex system and likely harbor potentially divergent perspectives and varying degrees of politically driven agenda projected onto complex systems, (3) scarce resources that are continually uncertain and subject to shift with little to no notice, resulting in disruption to stable resource planning, (4) constant shifts in performance expectations impacting the ability of a system to effectively respond, (5) advancing technology that can be disruptive and have difficulty integrating/interoperating with existing system technologies, potentially rendering once compatible support infrastructures obsolete, (6) stresses for urgency and near immediate responses to shifting system, context, or environmental demands, (7) emphasis on near term actions and results while surrendering the pursuit of long term stability in deference to immediate emerging crises, rendering long-term planning irrelevant, (8) the constant escalation of complexities and associated uncertainties that become status quo instead of more

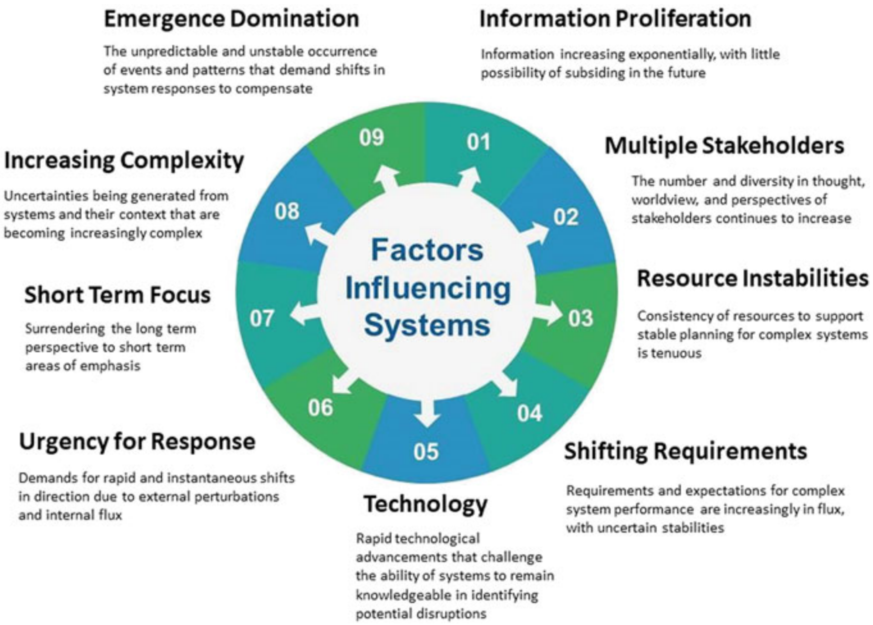


Fig. 1 Factors influencing complex systems

limited influences on system operation, and (9) emergence generating unpredictable patterns, structures, and behaviors that result in instabilities in planning, operation, and development of systems. These factors may seem somewhat unsettling and invite questions as to whether or not we will ever have the capabilities to effectively master this domain.

These factors are not likely to subside in the near future. Instead, they are more likely to escalate in frequency of occurrence and severity of impact. Future success in dealing with complex systems will be depending on the degree to which we can effectively mount a response in the face of these factors.

In short, the emerging ‘systems world’ is an increasingly ambiguous, complex, emergent world of interdependent systems fraught with instabilities and uncertainties [48–50]. There is a pressing need for a new mindset, capabilities, and skills that will increase the probability of success in dealing with complex systems. Unfortunately, ‘doing nothing’ is as unpalatable as continuing to suffer through the current state of complex system affairs.

Systems thinking can provide a valuable capability for addressing the factors laid out above. Although systems thinking is not the ‘silver bullet’, ‘magic elixir’, or ‘utopian solution’, it can add to the arsenal of weapons available to drive a different level of thinking, decision, action, and interpretation of responses.

This chapter is focused on the use of systems thinking to more effectively deal with increasingly complex systems and their problems. In general, systems thinking has been captured by Haines [33, p. vi] as ‘A new way to view and mentally frame what we see in the world,a worldview and way of thinking whereby we see the entity or unit first as a whole, with its fit and relationship to its environment as primary concerns; the parts secondary.'

At a fundamental level, systems thinking involves engaging complex systems from a worldview marked by a focus on the whole and relationships rather than the individual entities of a system. Thus, the behavior, structure, or performance outputs of a system are attributed to the interactions and interrelationships between entities rather than properties held by the component entities. This is fundamental to the perspective of systems thinking for CSG. Having a high level of systems thinking capacity is essential to deal with the conditions that define the nature of complex systems. If CSG is to achieve success, then systems thinking is fundamental to achievement of that success. Arguably systems thinking is the most critical enabling factor for CSG. If an appropriate level of systems thinking does not exist, it is doubtful that the expected contributions of CSG will be realized. Instead, the application of CSG with an inconsistent (nonsystemic/reductionist) worldview is not likely to secure the gains intended by a CSG endeavor. In fact, engaging CSG from a nonsystemic perspective may very likely do more harm than good.

In this chapter, the primary purpose is to explore the nature, role, and implications that systems thinking holds for CSG. The chapter is organized to achieve this purpose by exploring four fundamental points (Fig. 2).

First, systems thinking is examined. This examination is focused on providing an overview of systems thinking and setting the stage for application to CSG. Second, the specific role and relationship of systems thinking to CSG is discussed. The discussion

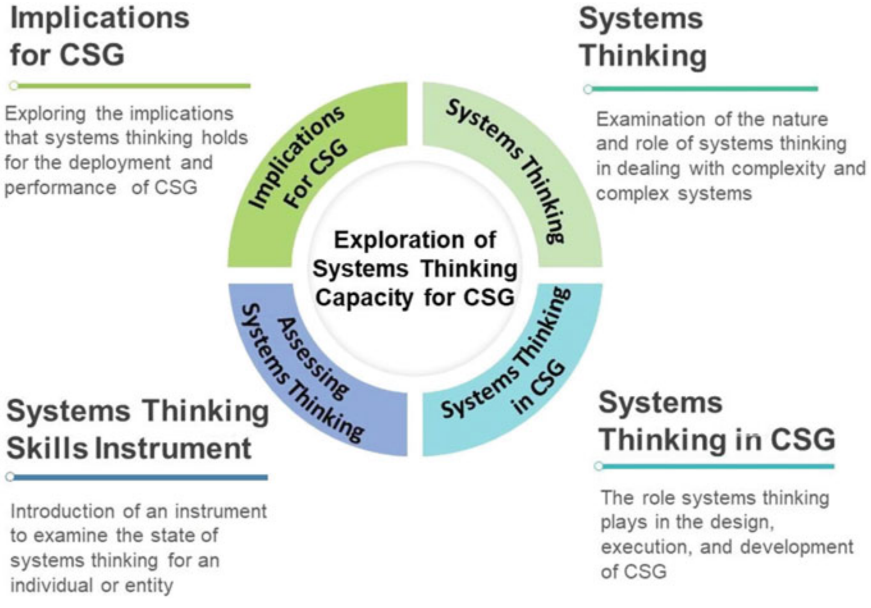


Fig. 2 Organization of the chapter

emphasizes the critical role that systems thinking plays in the design, execution, and development of CSG. Third, an instrument and approach for assessing the capacity of individuals and entities to engage in systems thinking is explored. The influence of this state of systems thinking is examined in relation to performance of CSG functions. Fourth, the implications of systems thinking for CSG are established. The chapter includes a section that provides the CSG instrument for application to assess the level of systems thinking capacity for an individual or entity.

2 Overview of Systems Thinking

Systems thinking is a high-level thinking skill that enables individuals to more effectively engage complex systems [65]. While much has been written about various perspectives of system governance [57], there is limited acknowledgement in the literature that addresses some of the most basic questions related to systems thinking in relation to CSG. The system thinking field has made significant contributions to the advancement of society and our ability to address complex issues. Systems thinking has been applied in such wide-ranging fields as organizational, biological, managerial, economic, and social [1, 12, 18, 21, 32, 36, 46, 58–60, 68, 73, 75, 76, 87, 90]. While the fields of application are different, the same underlying fundamental aspects of systems thinking are applicable across the fields. Again, focus on the whole as exhibiting properties not deducible or existing in the parts of making up the system.

Systems thinking is not entirely a new area. The concept has been in existence for some time, drawing on the earliest explorations found in the Chinese work *The I Ching or Book of Changes* [93]. This work dates to approximately 400 B.C. The *I Ching* noted the dynamic nature of changing relationships among elements, which is consistent with the most basic notions of systems thinking. The most fundamental tenet of systems thinking is found in *holism,* which recognizes the relationship between parts and wholes of systems. Holistic thinking can be found in some of the earliest writings of Aristotle (384–322 BC), who postured that there is more to the whole than that found in the parts [6]. Therefore, the essence of ‘systems’ and ‘systems thinking’ is found in interconnectedness and the whole-part distinction. Although there have been advances in society and systems thinking since the earliest works, the quest to understand interrelationships and behavior of wholes has certainly not waned. However, the debates surrounding complex ‘systems’ and our apparent limited ability to effectively and consistently address them remain unresolved, despite advances in our understanding of the related phenomena. Still yet, the challenges of effectively dealing with systems continue to persist. In Table 1, we list a representative set of perspectives that demonstrates a variety of viewpoints for systems thinking. This is not to suggest the superiority or preference of one perspective over another. Instead, what we can draw from this glimpse is the breadth of perspectives that exist for systems thinking.

Table 1 Multiple perspectives of systems thinking

Author	Perspective
Flood and Carson [28, p. 4]	'a framework of thought that helps us to deal with complex things in a holistic way.'
Checkland [20, p. 318]	'makes conscious use of the particular concept of wholeness captured in the word 'system', to order our thoughts.' 'An *epistemology* which, when applied to human activity, is based upon the four basic ideas*: emergence, hierarchy, communication, and control* as characteristics of *systems*. When applied to *natural* or *designed systems* the crucial characteristic is the *emergent properties* of the whole.'
Gharajedaghi [31, p. 15]	'puts the system in the context of the larger environment of which it is a part and studies the role it plays in the larger whole.'
O'Connor [67, p. 1]	'seeing beyond what appears to be isolated in independent incidents to deeper patterns.'
Haines [33, p. vi]	'A new way to view and mentally frame what we see in the world; a worldview and way of thinking whereby we see the entity or unit first as a whole, with its fit and relationship to its environment as primary concerns; the parts secondary.'
Senge [75, p. 89]	'a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static snapshots.' 'encompasses a large and fairly amorphous body of methods, tools, and principles, all oriented to looking at the interrelatedness of forces, and seeing them as part of a common process.'
Capra [17, p. 29]	'a new way of thinking … in terms of connectedness, relationships, context.'
http://www.opbf.org/open-plant-breeding/glossary/so-sz	'A system cannot be understood by an analysis of its parts. Systems thinking concerns the organisation of those parts, as a single system, and the emergent properties that emanate from that organisation.'
Richmond [73, p. 139]	'the art and science of making reliable inferences about behavior by developing an increasingly deep understanding of underlying structure.'

(continued)

Table 1 (continued)

Author	Perspective
ESD Symposium Committee [27], p. 8)	'includes holism, an ability to think about the system as a whole; focus, an ability to address the important system level issues; emergence (see below), recognition that there are latent properties in systems; and trade-offs, judgment and balance, which enable one to juggle all the various considerations and make a proper choice'
Davidz [26, p. 44]	'analysis, synthesis and understanding of interconnections, interactions, and interdependencies that are technical, social, temporal and multi-level'
Ackoff et al. [2, p. 6]	'looks at relationships (rather than unrelated objects), connectedness, process (rather than structure), the whole (rather than just its parts), the patterns (rather than the contents) of a system, and context.'
Arnold and Wade [7, p. 675]	'a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviors, and devising modifications to them in order to produce desired effects.'

Essential to understanding systems thinking is to understand the essence of systems theory from which systems thinking is drawn. This relationship shows that systems thinking draws from systems theory and is projected to application (Fig. 3).

Following the earlier work of Keating et al. [55], the following development of systems theory is suggested. Systems theory provides a strong conceptual foundation that can influence design, execution, and development of complex systems. Following works on systems theory [3, 52, 91], at a basic level systems theory can be described as a set of *axioms* (taken for granted truths about systems) and *propositions* (principles, concepts, and laws serving to explain system phenomena). Systems theory suggests several central tenets concerning the capacity to deal with environments marked by increasing complexity, instabilities, and ambiguity. These tenets include:

1. All systems are subject to the propositions of systems theory. These propositions define and serve to explain the structure, behavior, and performance of systems,
2. All systems perform a set of systems theory based system CSG functions that, subject to propositions, determine system performance,
3. Violations of system propositions in design, execution, or development of systems have consequences that degrade performance and produce failures in systems, and
4. Systems theory-based proposition violations can provide novel insights for better understanding the relationship of systems theory to inform systems thinking and CSG.

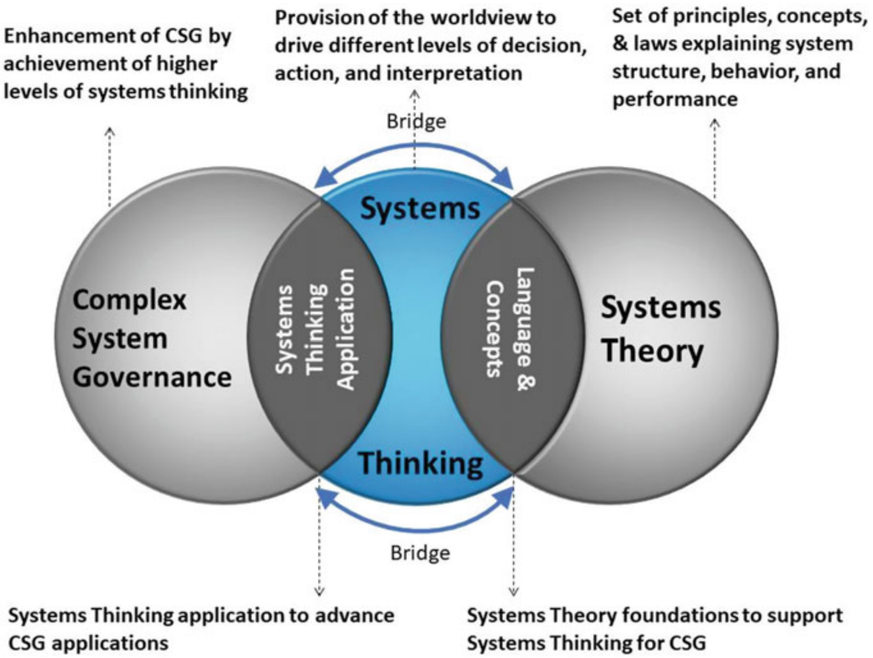


Fig. 3 Relationship of systems theory to systems thinking and CSG application

Further examination of systems theory inevitably leads to general systems theory (GST) to find its genesis. GST does not have a single common accepted definition. However, GST emerged in the 1940s as an attempt to provide an alternative to *reductionism*. *Reductionism* (focus on the successive 'breaking apart' to produce understanding) is closely aligned with the scientific method, which holds that a complex organism is understood as the sum of its parts, and therefore, they can be reduced to constituent elements [34, 55, 87]. In contrast to reductionism, *'holism'* suggests that understanding of a systems comes from the interrelationships between entities and cannot be ascertained from the properties of the parts. In essence, production properties that exist beyond those held by parts of the system.

An important delineation of systems thinking is the distinction between 'hard' and 'soft' systems thinking modes. Unfortunately, the distinctions between 'hard' and 'soft' set up the potential to view the classification as a binary either/or choice. However, in actuality, a complex system can have both hard and soft elements and arguably will invariably include different degrees of both. While the complete separation of hard and soft distinctions might be false, understanding their implications for systems thinking is important. This is particularly the case when there is the desire to 'rush to judgment' as to the source of deficient system behavior or performance in attributing the deficiency to either hard failure or soft failure. Table 2 provides a set of distinguishing system perspectives [40] that delineates the distinctions between the extremes of hard and soft thinking perspectives.

Table 2 Hard and soft systems thinking

Attribute	Hard system thinking	Soft system thinking
Understanding paradigm	*Reductionism*—focused on understanding through breaking apart (analysis). Performance of a whole can be understood as an aggregation of the properties of the parts	*Holism*—a system is only understood at the (irreducible) whole system level. The behavior of the whole cannot be ascertained simply from understanding the parts. Instead, understanding the system must include the interactions among parts that produce properties beyond those of the parts
Objective	*Optimization*—there is one best solution (optimal) for system performance. This is the solution or configuration which is sought	*Learning*—the primary function of system exploration is to learn about the system and be capable of mounting appropriate response(s) based on that learning to improve a situation
Methodology	*Systematic*—approach is defined by prescribed processes that can be replicated independently of context—prescriptive	*Systemic*—approach is a high-level guide that provides a general set of malleable directions—non-prescriptive and tailorable to circumstances and conditions
Goal/Objectives	*Clearly defined and agreed upon*—goals and objectives are assumed to be clear, unambiguous, defined, and stable	*Ambiguous and shifting*—clarity is not assured, and goals/objectives are subject to multiple interpretations and can be unstable
Perspectives	*Unitary*—assumes that there is an alignment of perspectives for the problem domain	*Pluralist*—there exist multiple, potentially divergent, perspectives on the problem domain
Contextual influences	*Low*—contextual influences are assumed to be 'minimized' by tight bounding of the problem	*High*—contextual influences are seen as integral, systems/problems are not easily separable from context, and boundaries are flexible
Environment	*Stable*—disturbances from the environment are minimal and the rate/depth of resulting changes are not considered overbearing on system solution	*Turbulent*—disturbances are potentially extensive and influence the ability to develop system solutions
Systems-of-interest	*Simple*—low number of variables, interactions well understood, behavior somewhat static or deterministic, environment stable	*Complex*—high number of variables, rich interactions not well understood, dynamic and uncertain, (emergent) pattern/behaviors, environment unstable
Modeling preference	*Mathematical/quantitative*—exact relationships and behavior mathematically predictable	*Non-mathematical/qualitative*—forms of representation non-quantitative in nature. Behavior is not precisely predictable

(continued)

Table 2 (continued)

Attribute	Hard system thinking	Soft system thinking
Boundaries	*Clearly delineated*—boundaries are definitive, stable, and understood	*Unclear and shifting*—boundaries are evolving, unstable, and ambiguous
Worldview	*Aligned*—divergence in worldviews not made explicit or considered central to understanding	*Potentially divergent*—divergence is considered highly probable, with an understanding of divergence sources critical to understanding
Defining metaphor	*Mechanistic*—clear understanding of predictable interrelationships	*Contextual*—lack of clarity in nature of interrelationships and external influences
Behavior	*Predictable*—system behavior is deducible from understanding historical patterns/trends and system interactions	*Emergent*—system behavior cannot be known in advance. Patterns of behavior/performance emerge through the operation of the system

For systems thinking, the inclusion of both hard and soft system thinking modalities is important. Both hard and soft systems thinking are required to engage in treatment of complex systems in a holistic fashion. Thus, the hard system aspects (generally technical, objective, and certain) as well as soft system aspects (generally non-technical, subjective, and uncertain) are necessary for a more holistic perspective of a complex system. Care must be taken not to treat a complex system existing as either

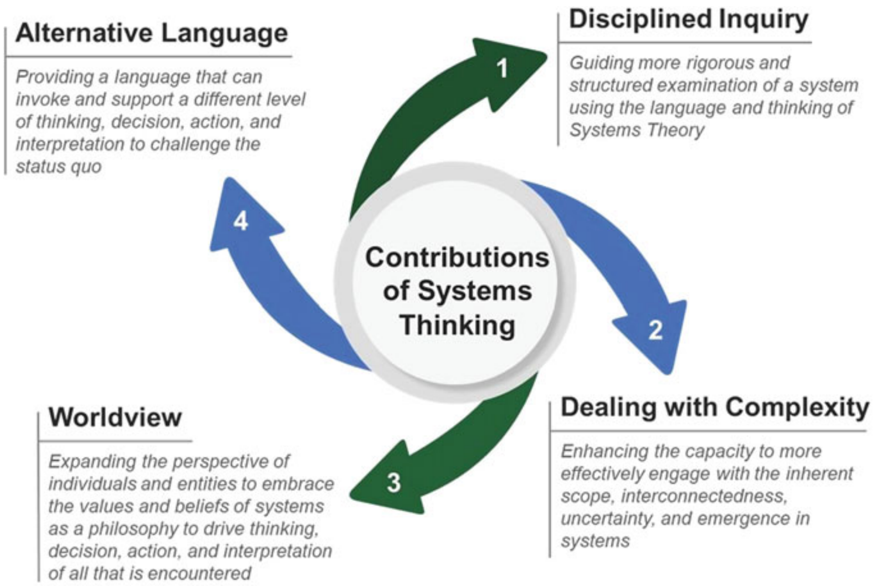


Fig. 4 Contributions of systems thinking

a binary hard or soft entity. In reality, complex systems include both perspectives and formulations. Additionally, the hard system elements influence the soft system elements and vice versa. Most assuredly, CSG must involve both forms of systems thinking and their interactions. To treat CSG otherwise would be shortsighted.

Since present and future environments of CSG are ever-changing, increasingly unstable, and complex, improved systems thinking abilities will be necessary to achieve increased capacity for dealing with complexity. In response, we suggest that systems thinking offers four important foundational contributions for CSG (Fig. 4).

These contributions are the essential offering of systems thinking, drawn from the underlying conceptual foundations of systems theory, including:

- **Disciplined Inquiry**—the application of systems thinking can be helpful in providing approaches, grounded in underlying systems axioms and propositions, to conduct more disciplined inquiry. The very nature of systems thinking suggests a more structured and orderly progression for understanding and holistic framing of complex interrelationships. This is an important point for individuals and entities that must develop effective understanding and governance for complex systems and their problems.
- **Dealing with Complexity**—dealing with increasing complexity is perhaps the greatest future challenge facing society. Systems thinking offers multiple approaches, based in underlying systems theory foundations, to more effectively address complex problems. Complexity is a fact of life for modern systems and their practitioners. The approaches to deal with complexity, rooted in a systems thinking frame of reference, can provide increased effectiveness in addressing increasingly complex systems and their constituent problems. CSG is one such approach.
- **Worldview**—worldview encompasses the values and beliefs that inform a philosophy for how the world functions and establishes the basis for making sense of what we perceive in the world. Aerts et al. (4, p. 9) suggest that ‘a worldview is a system of coordinates or a frame of reference in which everything presented to us by our diverse experiences can be placed.’ Thus, worldview is what Checkland [19] refers to as *weltanschauung*, the image or model of the world that provides meaning. In effect, the systems worldview offers a particular way of thinking that allows us to give meaning to actions, decisions, and events as they unfold. In effect, systems thinking can provide practitioners with increased capacity to ‘make sense’ of their circumstances and enhance the capability to mount more effective responses.
- **Alternative Language**—we think through language. Therefore, new language provides avenues for new thinking to more effectively deal with complex systems. The language of systems thinking can be instrumental in coming to a new understanding of familiar issues. Thus, new and different courses of action to address complex problems, both new and old, can be established.

The foundations for systems thinking are fundamental to CSG. Although there are many different formulations of ‘systems thinking’ in the literature, the importance this field holds for effectiveness in dealing with complex systems is clear. Having established the perspective and importance of systems thinking for CSG, we can now shift focus to developing greater detail into the specific nature and role that systems thinking plays in CSG.

3 Systems Thinking in CSG

Complex system governance (CSG) is a recently created field in a very early stage of development. CSG has been welcomed into the environment of theoretical complex system management due to its potential explanation of systems performance [53]. CSG is fundamentally identified as ‘the design, execution, and evolution of the meta-system functions necessary to provide control, communication, coordination, and integration of a complex system’ [53, p. 274]. CSG is a system-based approach that aims to enhance governance capabilities to achieve an effective management of complex systems. In other words, CSG is a capability that involves a set of actions required to improve the control of complex systems. Complex systems denote any system that contains an interrelated set of problems that cannot be easily resolved, understood, or formulated. Complex systems are an essential part of many diverse disciplines including economics, meteorology, biology, sociology, etc. [29, 30, 43, 71]. Therefore, enhancing governance of these systems is necessary to advance knowledge across disciplines beholden to complex systems.

The domain challenging present and future complex systems is becoming increasingly difficult to effectively govern (control). While the debate may ensue as to the source of the increased difficulty, the state of the current condition is much less questioned. A capture of the difficulties [51] that must be addressed in this domain is summarized by the following conditions and their impact:

(1) ***Hyperturbulent conditions***—the environment for complex system practitioners is highly dynamic, uncertain, and rapidly changing. This flux places traditional forms of dealing with complex systems in question. Stable platforms for providing control of complex systems from rational/logical designs are relegated to the past. A new era of complexity is here and not likely to subside in the future. This suggests that keeping up with these new conditions will require surrender of the ‘illusion’ of precision and metered approaches to greater reliance on approaches based in systems thinking-driven agility and resiliency.

(2) ***Ill-defined problems***—the luxury to precisely define problems enroute to developing cogent solutions is diminishing. The circumstances and conditions surrounding problems are potentially in dispute, not readily accessible, or lack sufficient consensus for initial problem formulation and bounding. This throws doubt on the capabilities of traditional approaches to adequately address these poorly understood, dynamic, and emergent problems. The ability to engage a ‘systemic perspective’ to frame problems is an important contribution that can be made by systems thinking.

(3) ***Contextual Dominance***—expectations must include that the technical 'hard' aspects of a problem may be overshadowed by the contextual 'soft' aspects. Contextual (soft) aspects are those circumstances, factors, conditions, trends, or patterns that influence the framing of the problem, solution development form, solution deployment, and interpretation of deployment results. Complex systems require more holistic treatment called for by systems thinking. Since in many cases, for highly volatile problem domains, context can play a more significant role than the technical aspects, a more holistic perspective provided by systems thinking is necessary.

(4) ***Uncertain approach***—increasingly, complex systems lack clarity on what the appropriate path forward might be to address problems. This calls into question standard approaches which have been successfully applied in the past. No longer are these approaches assured of success. Instead, agreement on the nature of the problem (framing), appropriate approach, and expectations for 'successful' resolution are potential sources of divergence. Systems thinking can be instrumental in better understanding the potential for more informed approaches.

(5) ***Ambiguous expectations and objectives***—given increasingly complex systems, the ability to establish measures of success, system objectives, or requirements is questionable. The conditions of inadequate understanding, incompatible perspectives, or lack of technical competence to proceed with the effort all serve to highlight ambiguity. Traditional thinking, mired in such monikers as 'do a better job', 'do more of the same', or 'work harder', is unlikely to realize any substantiation gains. Systems thinking can be instrumental in finding alternative frames of reference and corresponding paths forward in response to ambiguity.

(6) ***Excessive complexity***—complexity denotes a situation that is highly dynamic, uncertain, emergent, and containing a high number of richly interconnected elements/factors/variables. Dealing with this complexity lies beyond traditional approaches mired in a linear, reductionist perspective for their approach. Proceeding with traditional approaches would require significant reduction, assumptions, and potential oversimplification of the system and its problem domain. This creates the conditions for failure to meet expectations for problem resolution. In no sense should this be taken as a criticism of traditional approaches. On the contrary, traditional approaches, when applied to the right problem/context, have proven successful. However, given the evolving context of complex systems, the utility of traditional approaches must be questioned. Systems thinking brings a different, more holistic, perspective for framing complex system problems and offering alternative paths forward.

(7) ***Pluralist Perspectives***—a characteristic aspect of complex systems is the plurality of different perspectives. Many traditional approaches assume a 'unitary' perspective, where there is agreement on the nature of the problem, appropriate path forward, and expectations. However, for complex systems and stakeholders, the 'unitary' perspective assumption may be questionable. Thus, from a systems thinking perspective, complex systems must be

engaged with the understanding that multiple, potentially divergent, perspectives may well exist. Through the reframing of perspectives brought by systems thinking, appreciation of differences, true differences, and their joint exploration can be obtained.

(8) ***Extended Stakeholders***—stakeholders are individuals or entities that have a 'perceived' interest in the system or problem of interest. This suggests that complex systems can be fraught with a spectrum of stakeholders with different viewpoints. These perspectives may be convergent or divergent. However, systems thinking suggests that all perspectives should be included in the dialog. Thus, insights into the system/problem will not be unnecessarily bounded out.

(9) ***Emergence***—this suggests that until a system operates, the behavior, structure, and performance cannot be precisely known or predicted in advance. This implies that a different level of appreciation and understanding for complex systems must be invoked. In essence, the emphasis must shift from prescriptive detailed planning to planning that appreciates the continuous evolution of a system, its environment, and context. This dynamic 'emergence' of events and patterns cannot be predicted in advance. Thus, systems thinking suggests that designs be resilient (capable of returning to a level of performance following disruption) and robust (designed to accommodate a wide range of 'potential' disturbances without sacrificing performance).

(10) ***Ambiguous Boundaries***—boundaries for complex systems are arbitrary and subject to shifting with new knowledge or understanding. Likewise, the criteria for inclusion/exclusion can also dynamically shift over time. This does not suggest that establishment of boundaries is a fruitless endeavor. On the contrary, the establishment of boundary conditions is important to establish a reference baseline from which changes can be purposefully engaged. From a systems thinking perspective, the boundary conditions must be considered fallible, dynamic, and not absolute.

(11) ***Unstable Planning Foundations***—a high degree of uncertainty in complex systems renders traditional forms of planning of limited utility. For instance, there may be continual shifts in scarce resources, policies, directives, initiatives, and scenarios that create instabilities and make traditional planning difficult. Systems thinking suggests that planning is undertaken with the understanding that complex systems can, and will, shift over time and with new knowledge gained through operation.

(12) ***Information Saturation***—the proliferation of data and information continues to rise exponentially for complex systems. Knowledge of the design for data and information flows is critical to proper functioning of a system. As information is the lifeblood of a complex system, systems thinking is focused on ensuring that communications (flow and interpretation of information) are effectively designed, executed, and evolved to serve the needs of the system.

(13) ***Identity Coherence***—identity provides a reference point for a complex system. This reference point is the set of fundamental values, patterns, and attributes that define the essence of a complex system. Identity is the source

for consistency in decisions, actions and interpretations. Systems thinking is focused on supporting a strong identity such that there is a durable basis for understanding the attributes that are 'non-negotiable' in defining the essence of the system.

(14) ***Generational Shifts***—the generational shift in modern complex systems is well underway. This shift is predicated by the inevitable coming dominance of the millennial generation. For complex systems, this introduces additional strains and burdens in already overly complex systems. From a systems thinking perspective, this generational shift suggests that the incorporation of design modifications should be introduced to lessen the burden of the generational differences while capitalizing on designs that can take advantage of those differentials.

(15) ***Non-ergodicity***—complex systems are characterized by conditions of having no clearly defined states or discernible transitions between system states (Souza-Poza, et al. 2008). This suggests that systems are subject to inherent difficulties in understanding and provoking continuous transition to identified goals. Thus, traditional approaches based on a level of certainty and knowledge of cause–effect relationships is tenuous. Systems thinking suggests that operation in these conditions requires a degree of flexibility, being able to reconfigure as necessary to reset directions based on shifting conditions and understanding.

(16) ***Non-monotonicity***—the reality for complex systems is that increases in knowledge are not reciprocated by increases in understanding. Actions and decisions are always tentative [85]. This suggests that there must be a recognition that knowledge is necessarily provisional, incomplete, and fallible. The systems thinking perspective suggests the need to accept that the system is in continual flux, and allowances for perturbations from external and internal sources must be designed into the execution and development of a system.

The attributes above are certainly not suggested as an absolute or complete set. However, there are three important themes that are suggested for systems thinking for CSG. First, dynamic shifting in knowledge and understanding emerges over time as the system operates. Precise system knowledge designation the precise form, location, duration, or impact of emergent conditions cannot be known in advance. Second, our knowledge of a complex system must always be considered to be incomplete, fallible, and subject to change. This implies that design, execution, and development of a complex system cannot be precisely prescribed in advance. Care must be taken to limit the naïve assumption that the present state of knowledge/understanding will remain static and sufficient for future direction. Third, systems thinking provides a language, way of thinking, and alternative paradigm for dealing with increasingly complex systems and their problems. Following work in systems theory [3, 45, 54, 47, 91], we examine axioms and propositions that provide the language to inform systems thinking with implications for CSG. An axiom is taken as an accepted statement/concept that has been established over time and accepted without further explanation. Propositions are widely held concepts, laws, and principles that have

Table 3 Systems theory axioms, propositions, and implications for systems thinking in CSG

Proposition	Explanation	Implications for systems thinking in CSG
Centrality Axiom: Central to all systems are two pairs of propositions: emergence and hierarchy, and communication and control		
Communication [77, 78, 83]	Communication is a transaction between the information source terminal and the destination terminal, with the sole aim of generation and reproduction of symbols. Information is transmitted as a selection along possible alternative states	All CSG endeavors rely on communications—within designed systems, between systems and their environment, within the CSG function team, and with stakeholders. More rigorous understanding of communications can enhance CSG practice
Control [20]	The process by means of which a whole entity retains its identity and/or performance under changing circumstances	Control entails establishment of constraints and regulatory capacity in systems as well as their development processes. Design for system control impacts system robustness, resilience, viability, and fragility
Emergence [20, 6]	Whole entities exhibit properties and patterns that are meaningful only when they are attributed to the whole, not its parts	Emergence results in system patterns, behavior, or performance that cannot be predicted in advance. However, CSG practitioners can use emergence concepts to more effectively design, execute, and develop systems more adept at dealing with emergent conditions
Hierarchy [70, 20]	Entities meaningfully treated as wholes are built up of smaller entities which are themselves, wholes. In a hierarchy, emergent properties denote the levels	Appreciation of hierarchy implies CSG practice should organize large sets (e.g., data, requirements) into meaningful 'categorizations' which permits greater organization and actionable understanding
Contextual Axiom: System meaning is informed by the circumstances and factors that surround the system		
Complementarity [13]	Two different perspectives or models about a system will reveal truths regarding the system that are neither entirely independent nor entirely compatible	Considering multiple viewpoints and perspectives strengthens CSG practice. Accepting that there is a logic and assumptions that make alternative viewpoints correct, challenging logic/assumptions can enhance CSG dialogs and reduce unnecessary conflict

(continued)

Table 3 (continued)

Proposition	Explanation	Implications for systems thinking in CSG
Incompressibility [24, 72]	Each element in the system is ignorant of the behavior of the system as a whole and only responds to information that is available to it locally. As such, the best representation of a complex system is the system itself and that any representation other than the system itself will necessarily misrepresent certain aspects of the original system	All representations (models) are abstractions of a complex system, inevitably subject to abstraction error. Thus, CSG practice is enhanced by accepting incomplete and fallible knowledge and continually questioning appropriateness and evolving formulations based on new knowledge
Holism [84]	A system must be considered as a whole, rather than a sum of its parts	CSG practice must be deployed across the spectrum of technology, social, human, organizational, managerial, policy, and political dimensions. System failure can occur across this holistic spectrum, not just technology
Boundary [87, 83]	The abstract, semi-permeable perimeter of the system defines the components that make up the system, segregating them from environmental factors and may prevent or permit entry of matter, energy and information	Boundaries determine what is included/excluded for CSG efforts and should be made explicit through criteria for inclusion/exclusion. Compensation should be made for their change over time and shifts in conditions/understanding

(continued)

Table 3 (continued)

Proposition	Explanation	Implications for systems thinking in CSG
Design Axiom: system design is a purposeful imbalance of resources and relationships		
Minimal critical specification [22, 23]	This principle has two aspects, negative and positive. The negative implies that no more should be specified than is absolutely essential; the positive requires that we identify what is essential	Excessive constraint to regulate systems reduces autonomy and wastes scarce system resources. Care must be made to only constrain a system to the degree necessary to preserve outputs and outcomes desired
Power law [66]	The probability of measuring a particular value of some quantity varies inversely as a power of that number	CSG practice must anticipate nonlinear (exponential) relationships in complex systems. Tradeoffs in system performance are not in direct correspondence to either resources invested or effort expended
Requisite Parsimony [63, 82]	The capacity of human short-term recall is no greater than seven plus or minus two items	CSG practitioners should note human limitations to simultaneously focus on multiple factors. This suggests striving for the greatest simplicity possible in systems that are designed, operated, and evolved by people
Requisite saliency [14]	The factors that will be considered in a system design are seldom of equal importance. Instead, there is an underlying logic awaiting discovery in each system design that will reveal the significance of these factors	All characteristics (e.g., design parameters) are not of equivalent importance. CSG practice should provide clarity in criticality and priorities for making effective tradeoff decisions throughout the system lifecycle

(continued)

Table 3 (continued)

Proposition	Explanation	Implications for systems thinking in CSG
Goal Axiom: **systems achieve specific goals through purposeful behavior using pathways and means**		
Equifinality [86]	If a steady state is reached in an open system, it is independent of the initial conditions and determined by the system parameters, e.g., rates of reaction and transport	CSG practice must accept that there are alternative approaches that can produce equivalent results in CSG efforts. Execution of CSG is not achieved by one 'optimal' approach
Multifinality [15]	Radically different end states are possible from the same initial conditions	There are invariably different results that can occur in execution of CSG. Design for CSG must anticipate that circumstances and conditions can influence initial designs
Purposive Behavior [74]	Purposeful behavior is meant to denote that the act or behavior may be interpreted as directed to the attainment of a goal—i.e., to a final condition in which the behaving object reaches a definite correlation in time or in space with respect to another object or event	Designs in CSG should be clear in desired purpose related to fulfilling a need or addressing a problem. Irrespective of intent, system purpose is a function of utility (what a system provides)
Satisficing [80, 81]	The decision-making process whereby one chooses an option that is, while perhaps not the best, good enough	CSG practices should accept that, for complex systems, 'optimal' is not achievable (multiple possibilities can achieve desirable outputs/outcomes} nor desirable (unreasonable resources can be expended in pursuit of 'perfection')

(continued)

Table 3 (continued)

Proposition	Explanation	Implications for systems thinking in CSG
Information Axiom: Systems create, possess, transfer and modify information		
Information Redundancy [79]	The number of bits used to transmit a message, minus the number of bits of actual information in the message	Information in CSG processes should be designed with multiple pathways/mechanisms (redundancy) necessary to ensure both ‘receipt’ and intended ‘interpretation’ are met
Redundancy of Potential Command [62]	Effective action is achieved by an adequate concatenation of information	Decision authority in CSG should reside, to the greatest degree possible, at the point in closest proximity to where decision execution actions will be implemented
Operational Axiom: **Systems must be addressed in situ, where the system is exhibiting purposeful behavior**		
Dynamic Equilibrium [87, 64]	An entity exists as expressions of a pattern of processes of an ordered system of forces, undergoing fluxes and continuing flows of matter, energy and information in an equilibrium that is not static	CSG designs, processes, and activities are in constant flux, experience changing circumstances, and should be adjusted ‘on the fly’ to maintain stability in the face of change
Homeorhesis [88, 89]	The concept encompasses dynamical systems that return to an acceptable trajectory through adjustments in dynamic equilibrium controlled by interrelated regulation mechanisms	Key to CSG achievement is constant adjustment of the path toward a goal. Changes in external circumstances will require adjustment of trajectory – best by purposeful adjustment of regulatory mechanisms than by chance/crisis encounters
Homeostasis [16]	The property of an open system to regulate its internal environment so as to maintain a stable condition, by means of multiple dynamic equilibrium adjustments controlled by interrelated regulation mechanisms	CSG practice must provide adjustments to assure that key (internal) parameters maintain balance in response to inevitable internal flux that might impact ability to achieve CSG objectives

(continued)

Table 3 (continued)

Proposition	Explanation	Implications for systems thinking in CSG
Redundancy [69]	Means of increasing both the safety and reliability of systems by providing superfluous or excess resources	Sufficient mechanisms and resources should be allocated in a CSG effort to assure that achievement of objectives can be attained—given inevitable variabilities whose specific form cannot be know in advance
Relaxation Time [25, 37]	Systems need adequate time to recover from disorder that disturbs its equilibrium, at which point characteristic behavior resumes	Significant changes in CSG processes, design, or execution should be taken with clear understanding of the intent and determinants of success for the effort. Engaging multiple ‘changes’ can result in indeterminate sources of system oscillation (positive or negative)
Self-organization [8]	The spontaneous emergence of order out of the local interactions between initially independent components	Self-organization in CSG is an effective (least energy consuming) approach to design and execution. Patterns are permitted to emerge without interference (constraint) being invoked
Sub-optimization [35]	If each subsystem, regarded separately, is made to operate with maximum efficiency, the system as a whole will not operate with utmost efficiency	Integration of system elements requires surrendering of autonomy in favor of system integration. CSG practice should, by design, achieve a balance between subsystem autonomy and system integration

(continued)

Table 3 (continued)

Proposition	Explanation	Implications for systems thinking in CSG
Viability Axiom: Key parameters in a system must be controlled to ensure continued existence		
Circular causality [61]	An effect becomes a causative factor for future ‘effects’, influencing them in a manner particularly subtle, variable, flexible and of an endless number of possibilities	CSG practice must appreciate that some tightly coupled relationships cannot be broken into simple cause-effect understanding. Instead, these relationships can only be understood as a whole, not by breaking down
Feedback [92]	All purposeful behavior may be considered to require negative feedback. If a goal is to be attained, some signals from the goal are necessary at some time to direct the behavior	There is no perfect system design. Variabilities in deployment context require initiation of feedback to make corrections to account for variability impacting system outputs
Recursion [11]	The fundamental laws governing the processes at one level are also present at the next higher level	Irrespective of a particular system, the same system functions must be performed, subject to the same system propositions. If these functions are understood for one system, they are understood for all systems a CSG practitioner will encounter
Requisite Hierarchy [10]	The weaker in average are the regulatory abilities and the larger the uncertainties of available regulators, the more hierarchy is needed in the organization of regulation and control to attain the same result, if possible at all	CSG practitioners should ‘flatten’ the hierarchy through design of regulatory capacity to assure consistent performance (outputs/outcomes) and diminish uncertainty through design
Requisite Variety [9]	Control can be obtained only if the variety of the controller is at least as great as the variety of the situation to be controlled	The environment within which CSG is performed will generate disturbances (e.g., stakeholder requirement changes). CSG practitioners must provide a design that matches the types and quantities of disturbances that can be experienced

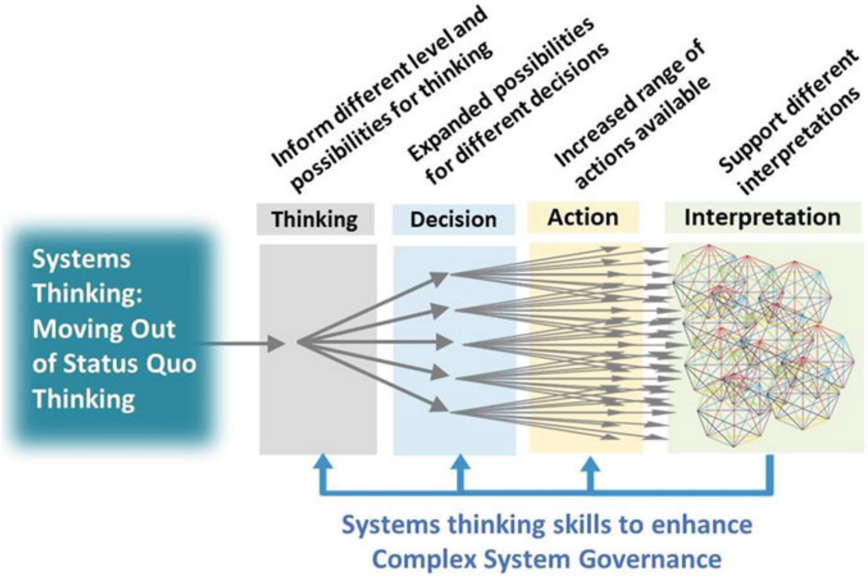


Fig. 5 Systems thinking moving beyond the status quo

been proposed in the systems theory literature, having withstood the test of time. Propositions are organized by associated axioms. Table 3 provides the axiom, associated propositions and implications for systems thinking in CSG. The axioms are drawn from the earlier work of Adams et al. [3] and subsequent amplifying works [54, 55, 91]. The propositions and explanations are drawn directly from the work of Whitney et al. Whitney et al. [91]. Our objective is to extend the propositions and thus bring systems theory closer to systems thinking implications for CSG.

The systems theory propositions provide the language for application of systems thinking for CSG. This language is essential to move to a different (systems) level of thinking. A different level of thinking is a precursor to engaging a corresponding different level of decision, action, and interpretation (Fig. 5). This is consistent with the formulation by Keating et al. [56], calling for movement out of the status quo trajectory pattern by using systems thinking to open the aperture for different thinking, decision, action, and interpretation.

4 Systems Thinking Capacity Assessment

Without doubt, systems thinking is critical to achieving and maintaining effectiveness in CSG.

There is some level of agreement on what systems thinking is for CSG, its importance, and implications. However, there is still the issue of how we go about determining the level of systems thinking for individuals and composite entities who will

Table 4 Seven dimensions of systems thinking capacity

Dimensions	Explanation
Interaction	Interconnectedness in coordination and communication among multiple systems and components
Independence	Balance between local level autonomy versus system integration
Change	Comfort with rapidly shifting systems and situations
Uncertainty	Acceptance of unpredictable situations with limited control
Complexity	Comfort with multidisciplinary and limited understanding
Systems worldview	Understanding system behavior at the whole versus part level
Flexibility	Accommodation of change or modifications in systems or approach

be engaging CSG. The ability to quantify an individual's systemic thinking potential is important in ensuring that participants involved with CSG development can effectively participate. Also, systems thinking capacity is an enabler, or constrainer, as to how prepared individuals may be to fulfill important roles in performing CSG functions. In this section, an approach to determine the level of systems thinking for an individual or entity is developed. This approach is referred to as systems thinking capacity (ST-Cap) instrument.

Based on earlier work by Jaradat [38–41], seven dimensions of systems thinking were developed. The ST-Cap instrument determines an individual's systems thinking capacity by analyzing seven separate dimensions of the individual's natural tendencies (following [40]) in relationship to systems thinking. The seven dimensions of systems thinking capacity are identified in Table 4.

Each of the dimensions has a range, spanning a spectrum from more or less systemic in their disposition. Table 5 identifies the range for each dimension. For each dimension, the left column indicates a propensity for a less systemic perspective. In contrast, the right column indicates a propensity for a more system perspective.

The seven systems thinking dimensions described above are used to establish a person's pre-dispositional thinking and determine their capacity to engage in the degree of systems thinking that is required by CSG. Individuals who exist more in the realm of *holism* are more likely to be more comfortable in dealing with unstable complex environments—this is a hallmark of complex systems and CSG. Although a lack of systems thinking capacity this does disqualify reductionist thinkers from working with complex systems, the high-end systems thinking required of CSG may place a development effort in a difficult situation. Lacking the sufficient systems thinking capacity, the probability for a successful CSG endeavor becomes increasingly doubtful. With respect to CSG, there are opportunities for all 'types' of systems thinking. Those who can focus on the broad 'systemic' aspects of the situation will be better suited to activities, task, and functions that call for heightened systems thinking capacity. Those without a lower level of systems thinking capacity may be better suited, and more comfortable, performing more narrowly defined and task focused activities.

Table 5 Systems thinking characteristics (based on [38, 40])

Systems thinking Dimension	Spectrum of individual systems thinking capacity characteristics	
	Less systemic	More systemic
Interaction	*ISOLATION (N)*—Inclined to local interaction, follow detailed plan, prefer to work individually, enjoy working in small systems, and interested more in cause-effect solutions	*INTERCONNECTIVITY (I)*—Inclined to global interactions, follow general plan, work within a team, and interested less in identifiable cause-effect relationships
Independence	*AUTONOMY (A)*—Preserve local autonomy, tend more to independent decision and local performance level	*INTEGRATION (G)*—Preserve global integration, tend more to dependent decision and global performance level
Change	*RESISTANT TO CHANGE (V)*—Prefer taking few perspectives into consideration, over specify requirements, focus more on the internal forces, like short-range plans and thinking, tend to lock in decisions, and work best in stable environment	*TOLERANT OF CHANGE (Y)*—Prefer taking multiple perspectives into consideration, under specify requirements, focus more on external forces, like long-range plans and thinking, keep decision options open, and work best in changing environment
Uncertainty	*STABILITY (T)*—Prepare detailed plans beforehand, focus on the details, uncomfortable with uncertainty, believe work environment is under control, enjoy objective, and technical problems	*EMERGENCE (E)*—React to situations as they occur, focus on the whole, comfortable with uncertainty, believe work environment is difficult to control, enjoy subjectivity, and non-technical problems
Complexity	*SIMPLICITY (S)*—Avoid uncertainty, work on linear problems, prefer best solution, prefer small scale problems	*COMPLEXITY (C)*—Expect uncertainty, work on multidimensional problems, prefer a working solution, and explore the surrounding environment
Systems worldview	*REDUCTIONISM (R)*—there exist multiple, potentially divergent, perspectives on the problem domain	*HOLISM (H)*—assumes that there is alignment of perspectives for the problem domain
Flexibility	*RIGIDITY (D)*—prefer not to change, like determined plan, motivated by routine	*FLEXIBILITY (F)*—accommodate change, like flexible plans, open to new ideas, unmotivated by routine

The ST-Cap instrument, based on Jaradat's research 38, is a 39 question instrument to establish the capacity for an individual to engage in systems thinking. This instrument represents an important advance in the determination of systems thinking capacity for individuals and entities contemplating engaging CSG. The section below titled 'Systems Thinking Capacity Instrument' provides the full instrument and classification schema.

The ST-Cap instrument provides a 'baseline' snapshot for individuals. In addition, the results of the group of individuals participating in a CSG initiative can be aggregated across their systems thinking profiles. This aggregation provides a locus of systems thinking of the group as well as the distribution of the range of thinking (diversity of thinking) held by the group. In this sense, the aggregate mean and variance for the group distribution across the seven dimensions provide an indicator of the level of systems thinking available in the group. Low levels of systems thinking capacity may indicate that a group needs to first increase the capacity for systems thinking prior to more comprehensive engagement in CSG.

Vignette – We are Agile, but not Flexible?

A production division of a company took the ST-Cap instrument. The division was touted as being based in an agile paradigm. This entailed being able to quickly adapt and improvise to meet shifting demands and changes to products and customer preferences. The group was perplexed when the results of the ST-Cap were tabulated. The group was scored rather low on the flexibility dimension. The result represented the antithesis of what had been continually projected as the central paradigm upon which the system was designed and operated. Through successive exploration, the confounding discovery was examined and the realization that the system was in fact lacking substantial flexibility in being adaptive to shifts in the environment and dealing with internal flux within the system. The effort pointed out the danger of announcing to the world the possession of a particular trait without the substantial evidence to conclude that it actually existed in the system.

There is significant reliance on the systems thinking capabilities of the individuals implementing CSG deployment. These individuals must be capable of mustering the systems thinking capacity to effectively engage CSG at the level of thinking, decision making, and interpretation that is congruent with advancing the state of CSG development. It is important to note that systems thinking and the ST-Cap assessment have been deployed outside of the CSG domain. The implementation of systems thinking is predicated on the (1) systems thinking capacity of the individual acquired naturally or through training, education, or experience, and (2) determination of the predisposition of an individual toward a systemic perspective. This draws a close coupling of an individual's capacities regarding systems thinking with their potential for effectiveness engaging CSG.

Beyond CSG, systems thinking has been implemented in several fields desiring to assess the capabilities of individuals to engage in systems thinking. It is not a foreign concept to assess individuals across dimensions, preferences, and tendencies to identify congruence of individuals to the work they are tasked to perform. As workplace demands for greater systems thinking capabilities increases, the emphasis on conducting assessment of those capabilities also rises. Matching the employees with the demands of assigned tasks and the environment within which those tasks must be performed is critical. It is costly to require individuals to engage in systems thinking based tasks for which they are not adequately suited. Following this perspective, several organizations have used the ST-Cap instrument to better understand the congruence between individual, work, and the environment. For instance, in a recent case study by Karam et al. [44], the ST-Cap instrument was applied in a large U.S. organization to demonstrate how it might aid in selection of future employees to be more compatible with the complexity in their job demands. In the study, two instruments were used to assess individual congruence to work. First, the ST-Cap provided an indicator as to the capability for systems thinking. Second, the complexity demand of the environment was assessed along the same dimensions as the ST-Cap. The result was used to show the differentials along each system's thinking dimension compared to that demanded by the work environment. Thus, the ‘fit’ of an individual to the tasks they would be performing could be established. The matching of individual ST-Cap and Environmental Complexity Demand was used to assess the match of the employees to the organization’s needs [44].

The ST-Cap instrument has also been used in another study by Jaradat et al.[42]. In this study, the ST-Cap instrument was used to compare systems thinking skills across three different sectors, including ‘Academic/government’ ‘Industry/business,’ and ‘Military.’ This study had a sample size of 273 individuals that was comprised of systems engineers and engineering managers, with various levels of expertise, with each of the sectors represented in the sample (100 academic/government, 117 industry/business, and 56 military spanning 25 different organizations). The study findings demonstrated the capability of the ST-Cap instrument to identify and contrast the systems thinking capacity across the three different sectors. Ultimately, the study concluded that the military domain is highly governed by a systemic (holistic)-based profile, while the other two sectors are in between holistic and reductionist profiles [42].

Although the ST-Cap instrument continues to be refined, it has been shown to be a useful indicator of an individual capacity for systems thinking. While this is critical for CSG, systems thinking also has applicability across multiple different contexts where complexity requires heightened capabilities for systems thinking.

5 Implications of Systems Thinking for CSG

Systems thinking is critical to effective deployment of CSG. The language provided by systems thinking (drawn from systems theory) provides the leverage to move to a different level of thinking. This different level of thinking is instrumental in providing the foundations to engage in, and develop, a different corresponding set of decisions, actions, and interpretations in response to increasing complexity.

Determining individual capacity for systems thinking has several important implications for CSG development. First, having an appropriate level of individual/group systems thinking capacity is critical to CSG development. Ultimately, CSG development will be designed, executed, and evolved by individuals. Their capacity to engage in systems thinking will have a profound influence on the speed, depth, and sustainability of CSG development. The CSG development methodology is targeted to *initialization, mapping, and development stages.* At each stage of this methodology, systems thinking is a critical influence. As Fig. 6 indicates, there is a circular causal loop where systems thinking informs CSG Development and CSG Development enhances the level of systems thinking (permitting increasing sophistication in decision, action, and alternative options).

Following Jaradat and Keating [40], systems thinking provides a current baseline of systems thinking held in the system of interest, helps determine what might feasibly be undertaken for CSG development given the current state of systems thinking,

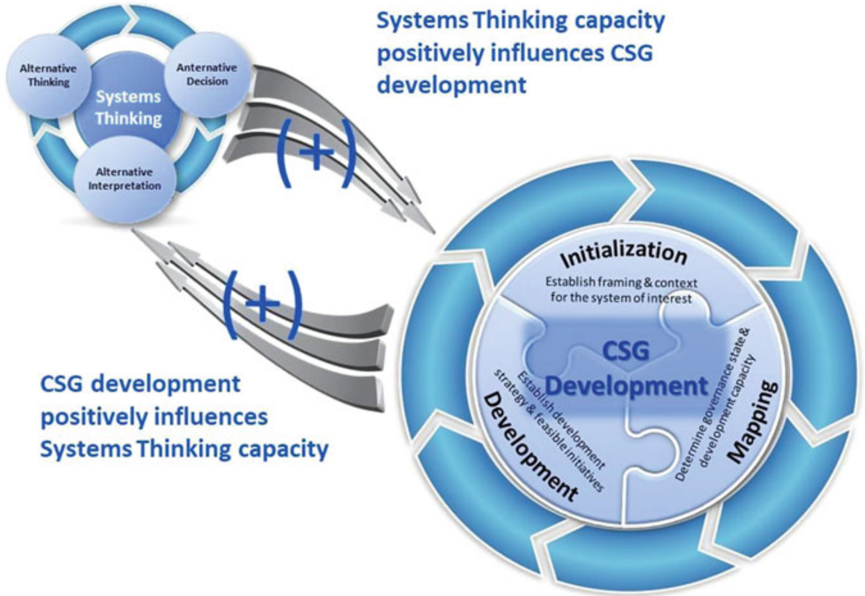


Fig. 6 Circular causal relationship between systems thinking and CSG development

and supports alternative decisions, actions, and interpretations for CSG development. In response, CSG development provides a maturing systems thinking capacity through the development approach, suggests enhancements to systems thinking identified during development, and benefits from enhanced systems thinking supporting increasingly sophisticated CSG development initiatives.

A second implication of systems thinking for CSG involves helping to determine what can feasibly be undertaken with respect to system development. System development activities are constrained by the degree of sophistication (maturity) that exists in the systems thinking capacity held by individuals and the system of interest. If sufficient systems thinking capacity does not exist, then the probability of success for development initiatives requiring systems thinking capacity beyond that available, will likely fall short of expectations. Take for instance a case where a CSG development initiative requires a 'high' level of individual capacity for systems thinking. Further, that the 'high' level is not held by individuals, or within the group, who will assume responsibility for execution of the initiative. The conclusion is that the probability for success in the execution of the initiative is suspect. This does not suggest that at later points in CSG development, the systems thinking capacity will remain at an insufficient level. As CSG development escalates, so too does the increasing capacity for systems thinking. Thus, additional development possibilities to engage 'higher' level CSG development initiatives advances as systems thinking capacity advances.

There are several system thinking challenges that practitioners should consider for deployment of CSG. Each of these challenges represents areas of consideration that might enhance effectiveness of CSG development—but are certainly not prescriptive as a recipe for success in CSG. Systems thinking, while presented as essential to be assessed in the front-end of a CSG development effort, in actuality operates throughout the design, execution, and development stages of CSG. Thus, the degree of systems thinking limits or enhances every aspect of the design, execution, and evolution of CSG. To capsule the system thinking challenges inherent in CSG, the following six challenges, stemming from earlier work of Jaradat and Keating [40] are provided to better appreciate systems thinking considerations for CSG. Among these challenges and their implications for systems thinking in CSG development are:

(1) *Systems Thinking Capacity*—for a system of interest, there is a level of systems thinking capacity that exists for both individuals and the collective group responsible for CSG functions. For individuals, Jaradat's [38] Systems Thinking Capacity instrument is useful as a 'snapshot' of the individual capacity for systems thinking. Although a good start, it cannot be taken as more than an invitation to deeper examination of the prevalence of systems thinking. Beyond the individuals, the larger system should also be considered as to the level of systems thinking that exists at the aggregate level. This aggregate should also include the variability (diversity) in thinking across the aggregate. Ultimately, the success of endeavors to enhance CSG are subject to the match between the degree of systems thinking existing in the system of interest and the level of systems thinking demanded by the development activities undertaken. A mismatch between CSG development activities and the required level of systems thinking capacity is not likely to produce the results desired.

(2) *Support Infrastructure Compatibility with Systems Thinking*—CSG development is unlikely to ever be a 'clean sheet' effort. Instead, it is more likely that CSG development will be deployed for an existing system of interest. Thus, there is already an existing infrastructure in place (e.g., processes, support systems, functions, mores, paradigm) that constrains/enables the system of interest. Engaging systems thinking cannot be accomplished independent of the constraining, as well as enabling, capacity that the system infrastructure provides for CSG development. Compatibility is always necessary between the support infrastructure and the systems thinking capacity required for initiatives undertaken to achieve success in CSG development initiatives. Without this compatibility, limiting infrastructure must be evolved such that sufficient compatibility exists to ensure that CSG development initiatives are feasible given the support infrastructure. Irrespective of the 'goodness' of ideas stemming from systems thinking engagement, failure to account for the impacts of supporting infrastructure is shortsighted. The result of incompatible infrastructure can be failure to achieve the full potential of CSG initiatives.

(3) *Continual Development of Systems Thinking Capacity*—in the initial stages of CSG, development a ‘snapshot’ of system thinking capacity is constructed. However, systems thinking does not exist in a static state. Care must be taken to actively advance the state of systems thinking at both the individual as well as the system levels. Active development of systems thinking capacity should be by purposeful design as well as systems thinking that emerges through the routine application of CSG development. Simply relying on a ‘snapshot’ of systems thinking capacity is not sufficient. Complacency with the ‘snapshot’ of systems thinking capacity is an invitation to make faulty conclusions concerning the nature and types of CSG development activities that can be undertaken. Also, it is not sufficient to simply take a ‘snapshot’ of systems thinking and conclude that no further development is necessary. Continual development and advancement of systems thinking should be a central element for holistic CSG development.

(4) *Building Sustainable Foundations for Systems Thinking*—building systems thinking capacity lies beyond the shortsighted perspective of learning new tools or attending training events. Getting the most from systems thinking requires practitioners to continually be immersed in the language and thinking stemming from foundational propositions of systems theory. There will always be new tools and techniques that emerge to support systems thinking. However, when systems thinking is grounded in underlying foundations (e.g., systems theory propositions), the lasting impacts will be more pronounced, widely applicable, and sustainable. In this sense, systems thinking will withstand the tests of time and better inform CSG development.

(5) *Appreciation of Uniqueness, not Prescriptive Application*—systems thinking is largely about generating shifts in thinking such that alternative decisions, actions, and interpretations can be developed. Thus, for achievement of this shift, there is not a prescriptive formula, approach, or universal method that can assure repeatable success. Instead, each complex system, context, and set of practitioners are unique for each system of interest. Therefore, this uniqueness invokes the necessity to engage in an equally unique approach to development of systems thinking capacity. In short, there is not a ‘one size fits all’ approach that can be taken to develop systems thinking capacity. Practitioners must appreciate that every complex problem is unique and exists in a unique context. Thus, both systems thinking, and CSG informed from systems thinking, will miss the mark if they are deployed prescriptively. Instead, they must be tailored to the uniqueness of the system of interest, context, and set of practitioners deploying CSG.

(6) *Shifting from Thinking to Action*—systems thinking invites CSG practitioners to explore complex situations in a way that allows for framing and reframing from different perspectives. The most fundamental system questions are explored from an underlying system thinking perspective. Questions about boundaries, relationships, and behavior are cast from the perspective of the language and thinking of systems. These questions, engaged from a systems thinking perspective, gain the advantages that non systems-based approaches

> and perspectives cannot bring to complex systems. However, there is a distinction between thinking and action. Thinking only creates the potential for initiation of action, not the action itself. Care must be taken to appreciate the gap between what can be generated at a 'thinking'-level versus what can be 'feasibly engaged' at the action level for CSG development. For CSG, active management of this gap is essential. Thinking without action is insufficient to develop CSG. 'Thinking alone' will only create the potential for corresponding action. Additionally, caution must be taken as to not limit thinking. However, there must also be an emphasis on not creating unrealistic expectations concerning what can be feasibly achieved in CSG development.

Systems thinking is not a cure-all that can address all problems and guarantee successful CSG endeavors. However, systems thinking invites practitioners to engage CSG development from a different level of thinking. The different level of thinking is appropriate and applicable throughout all stages of CSG development [50]. The criticality of systems thinking, as well as the systems thinking capacity for both individuals and system of interest participants, cannot be overstated for CSG development. The crux of systems thinking lies in the entirely different range of decisions, actions, and interpretations that become accessible in pursuit of CSG development.

6 Systems Thinking Capacity Instrument

This instrument includes 39 items. Each item should be completed by circling the response that best describes your preference. Following the last item, complete the scoring sheet.

1. To address system performance focus should be on
   (a) individual members of the system
   (b) interactions between members of the system
2. Do you prefer to work with
   (a) few systems or people
   (b) many systems or people
3. Are you most comfortable developing a
   (a) detailed plan
   (b) a general plan
4. Do you prefer to
   (a) work individually on a specific aspect of the problem
   (b) organize a team to explore the problem

5. With respect to system interactions, at which level would you prefer to focus
   (a) locally
   (b) globally
6. Do you feel more comfortable working
   (a) individually
   (b) in a group
7. Which is more important to preserve
   (a) local autonomy
   (b) global integration
8. Decisions should be made
   (a) independent of the system
   (b) dependent on the system
9. Parts in a system should be more
   (a) self-reliant
   (b) dependent
10. Giving up local decision authority should be
    (a) resisted
    (b) embraced
11. Performance is determined more by actions at the
    (a) local level
    (b) global level
12. Do you prefer to think about the time to implement change in a system as
    (a) short
    (b) long
13. Change in a system is most likely to occur as
    (a) revolutionary
    (b) evolutionary
14. In turbulent environments, planning for system change is
    (a) useful
    (b) wasteful
15. Forces for system change are driven more
    (a) internally
    (b) externally

16. To evolve a system, would you prefer to find
    (a) One best approach
    (b) Multiple possible approaches

17. To ensure system performance, it is better to
    (a) overspecify requirements
    (b) underspecify requirements

18. Would you most prefer to work in group that
    (a) prepares detailed plans beforehand
    (b) reacts to situations as they occur

19. You prefer to focus more on the
    (a) specific details
    (b) whole

20. In dealing with unexpected changes, you are generally
    (a) uncomfortable
    (b) comfortable

21. Control of the work environment is
    (a) possible
    (b) not possible

22. I prefer to work on problems for which the solution is
    (a) objective
    (b) subjective

23. I most enjoy working on problems that primarily involve
    (a) technical issues
    (b) non-technical issues

24. Are you more inclined to work on something that follows
    (a) regular patterns
    (b) irregular patterns

25. Once desired performance is achieved, a system should be
    (a) left alone
    (b) adjusted

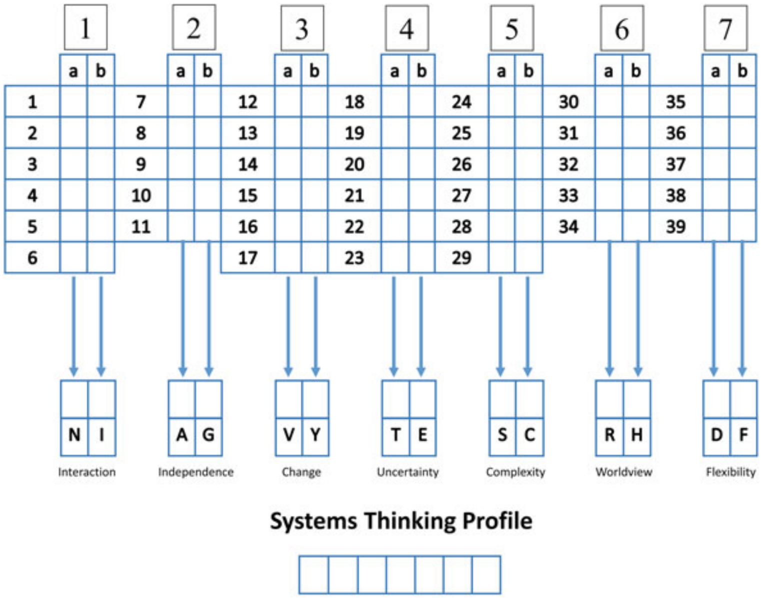
26. In dealing with a system, would you prefer it io be
    (a) small
    (b) large

27. I prefer to work on problems for which the approach is
    - (a) standardized
    - (b) unique
28. In solving a problem, I generally try to get opinions from
    - (a) a few people
    - (b) many people
29. A solution to pProblem should always be
    - (a) the best solution
    - (b) a working solution
30. A system can be understood by analyzing the parts
    - (a) agree
    - (b) disagree
31. In thinking about this system, I would prefer to focus on
    - (a) particulars
    - (b) the whole
32. System performance is primarily determined by individual components
    - (a) agree
    - (b) disagree
33. A problem should first be addressed at what level
    - (a) specific
    - (b) general
34. Once successful, a technical solution will result in similar success in other applications
    - (a) agree
    - (b) disagree
35. I am most comfortable working where circumstances require
    - (a) minimal adjustment
    - (b) constant adjustment
36. Once a system is deployed, modifications and adjustments indicate that the design was
    - (a) inadequate
    - (b) flexible

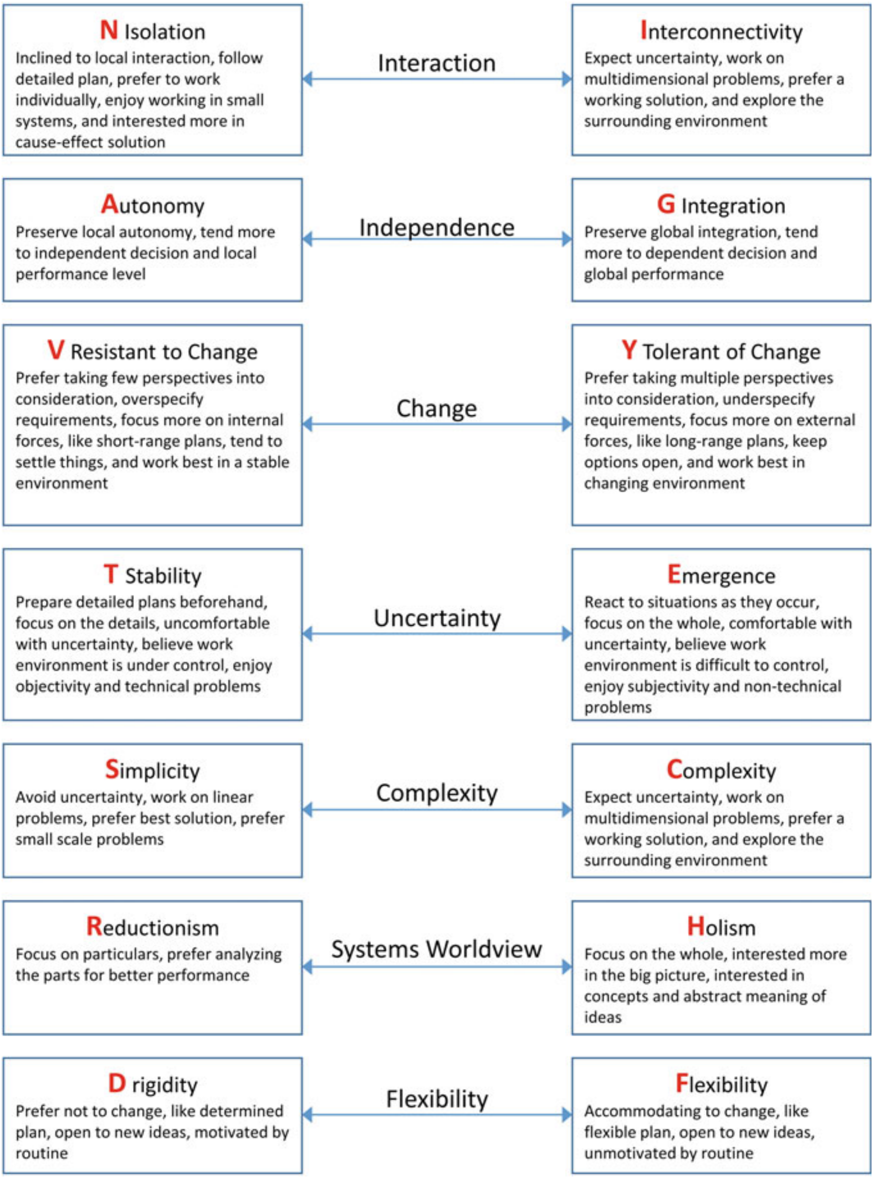
37. In planning for a system solution, plans should be
    (a) fixed
    (b) expected to change
38. With respect to execution of a plan
    (a) I prefer to follow the plan as closely as possible
    (b) I am comfortable with deviating from the plan
39. I would describe my preferred work environment as one for which outcomes
    (a) are predetermined
    (b) emerge

Directions for scoring:

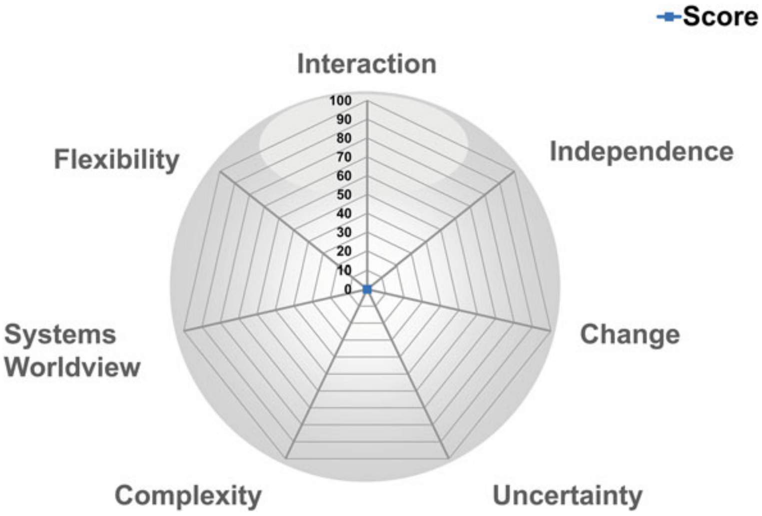
1. For each question, check the ‘a’ or ‘b’ block.
2. Add the total number of ‘a’ answers in the box at the bottom of each column. Do the same for the ‘b’ answers.
3. There are now seven pairs of numbers.
4. Circle the letter below the larger of the numbers of each pair.
5. Place the letter in the six boxes below the pairs (in the order from left to right).
6. These combinations identify the individual’s systemic thinking preference profile.
7. The complete profile is the seven letter combination from the fourteen letters.
8. For the ‘b’ column in each dimension, divide the number of ‘b’ responses by the number of questions (e.g., for Dimension 1, if there were 4 ‘b’ responses, it would be (4 ‘b’ responses)/6 Total Questions = 0.66 or 66%. Record this number on the corresponding ‘radar chart’ for each dimension. For any that are evenly split mark both letters. For example, if Complexity has 3 “a” responses and 3 ‘b’ responses, then the profile letter would be S/C.



Calculation aid	
5ths	Percentage
1/5	20
2/5	40
3/5	60
4/5	80
5/5	100
6ths	
1/6	17
2/6	33
3/6	50
4/6	67
5/6	83
6/6	100



N Isolation Inclined to local interaction, follow detailed plan, prefer to work individually, enjoy working in small systems, and interested more in cause-effect solution	Interaction	**Interconnectivity** Expect uncertainty, work on multidimensional problems, prefer a working solution, and explore the surrounding environment
Autonomy Preserve local autonomy, tend more to independent decision and local performance level	Independence	**G Integration** Preserve global integration, tend more to dependent decision and global performance
V Resistant to Change Prefer taking few perspectives into consideration, overspecify requirements, focus more on internal forces, like short-range plans, tend to settle things, and work best in a stable environment	Change	**Y Tolerant of Change** Prefer taking multiple perspectives into consideration, underspecify requirements, focus more on external forces, like long-range plans, keep options open, and work best in changing environment
T Stability Prepare detailed plans beforehand, focus on the details, uncomfortable with uncertainty, believe work environment is under control, enjoy objectivity and technical problems	Uncertainty	**Emergence** React to situations as they occur, focus on the whole, comfortable with uncertainty, believe work environment is difficult to control, enjoy subjectivity and non-technical problems
Simplicity Avoid uncertainty, work on linear problems, prefer best solution, prefer small scale problems	Complexity	**Complexity** Expect uncertainty, work on multidimensional problems, prefer a working solution, and explore the surrounding environment
Reductionism Focus on particulars, prefer analyzing the parts for better performance	Systems Worldview	**Holism** Focus on the whole, interested more in the big picture, interested in concepts and abstract meaning of ideas
D rigidity Prefer not to change, like determined plan, open to new ideas, motivated by routine	Flexibility	**Flexibility** Accommodating to change, like flexible plan, open to new ideas, unmotivated by routine



7 Summary

In this chapter, the nature, role, and implications of systems thinking for CSG development have been introduced. Systems thinking provides an important foundation for the design, execution, and development of complex systems. In essence, systems thinking is a critical skill set to have for effectiveness in CSG. Systems thinking was presented from the perspective of providing an individual, and entities, capacity to more effectively deal with the inherent complexity, uncertainty, ambiguity, and emergence that are characteristic of complex systems.

The basis for systems thinking is grounded in the underlying worldview of *holism*. For CSG, holism suggests that pursuit of CSG development must be targeted to understanding system behaviors as a function of not only the entities that comprise the system but also of their interactions. Additionally, the tenets of systems thinking were presented as grounded in the underlying language of systems theory. This language of systems theory provides the basis for moving to a different level of thinking. Subsequently, this different level of thinking enables a different decision space to emerge, different corresponding potentials for actions to enact decisions, and a different range of interpretation accessible to understand ‘differently.’ Also, systems thinking creates the conditions for engaging in: (1) more disciplined inquiry, grounded in the underlying axioms and propositions of systems theory that enable a different level of understanding of complex system behavior, structure, and performance, (2) support for more effective engagement to deal with increasingly complex systems and their problems, (3) exposure to an alternative language to assist in framing complexity, complex systems, and problems in different ways, and thus opening unforeseen possibilities for resolution, and (4) exposure to a different worldview, inviting movement to a different interaction, interpretation, and understanding to all that is encountered with respect to complex systems. Thus, the reach of systems thinking, while essential to effectiveness in CSG, has a range that far exceeds implications for CSG alone.

Also noted in this chapter is the essence of systems thinking capacity and its potentially enabling, as well as disabling, influence on CSG. Systems thinking plays a critical role in the 'front-end' framing for CSG development. It is noteworthy that systems thinking is not a panacea of effectiveness that can guarantee universal success. On the contrary, it is one aspect, albeit a critical aspect, in foundations essential for effective CSG development. Additionally, the relationship between systems thinking and CSG development was examined as reciprocal in nature. Systems thinking enhances prospects for CSG development. Likewise, CSG development is instrumental in enhancing the state of systems thinking for a system of interest. Each influences, and is influenced by, the other.

Systems thinking capacity was introduced as an approach to establish the level of systems thinking for an individual or set of individuals. The ST-Cap instrument consists of 39 questions that provide an indicator of the level of systems thinking. While the results of the ST-Cap instrument must be considered a 'snapshot' of systems thinking, it does provide an 'indicator' as to the state of systems thinking along the seven dimensions of systems thinking assessed. Also, systems thinking is not static and efforts for CSG development can also include purposeful development of systems thinking.

Systems thinking was suggested as an essential aspect of CSG development. Absent an appropriate level of systems thinking, the prospects for successful CSG endeavors are questionable. Additionally, systems thinking is not a static indicator, but rather something that can and will shift over time as CSG is developed. Implications for systems thinking were proposed, primary among which was the need to move from 'thinking' to 'action' based on the insights and understanding generated from systems thinking. Systems thinking has wide-ranging implications for CSG and exists as a cornerstone for CSG development.

Exercises

1. For complex systems, describe the distinction between 'hard' and 'soft' systems aspects and discuss the implications for 'holistic' treatment for CSG development.
2. Complete the ST-Cap assessment instrument in the section titled 'System Thinking Capacity Instrument.' Identify your 7 letter profile for systems thinking.
3. Based on your ST-Cap assessment profile, discuss the implications of your profile for engaging systems thinking. Where might you have developmental areas or potential 'blind spots' suggested from your profile?
4. Discuss the role that systems thinking plays in CSG and CSG development.

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