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How to Find Systems Thinkers

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Abstract

The problems associated with increasing complexity continue to impose challenges in understanding and managing complex system problems and thus, there is an emerging need to identify individuals who are capable of dealing with modern systems. At a fundamental level, systems thinking can offer new ways of thinking 'systemically' to effectively deal with the complex problems faced by many professionals. There is a lack of research-based instrument(s) in the literature that identify individuals' fitness for systems thinking. This paper introduces the development of a systems thinking instrument that identifies individuals capacity for systems thinking and determines their inclination in treating complex system problems across domains. This instrument can also be used to distinguish where a university curriculum (or a corporate training program) excels at producing systems thinkers and where it may be lacking.

Introduction

In 2016, the World Economic Forum published a report on how workforce dynamics will change over the next five years, including what skillsets will be most important for employees to have.[1] Table 1 below illustrates this change by comparing the current top three skills, identified in a 2015 survey, with research-supported predictions for 2020. While complex problem solving will remain a necessary skill, critical or systems thinking and creativity will both become more and more important in solving complex system problems. As new technologies transform industries, these skills will enable the mental flexibility needed to interact with increasingly complex systems.

Table 1: Top Three Skills for Employees[1]

	In 2015	**In 2020**
1	Complex Problem Solving	Complex Problem Solving
2	Coordinating with Others	Critical Thinking (Systems Thinking)
3	People Management	Creativity

Complex systems are marked by increased levels of uncertainty, interconnectivity, evolutionary development, integration, and ambiguity. These attributes are likely continuing to confound our capability to understand and solve complex problems. In effect, there is a need for qualified individuals—educators, engineers, leaders, and others—who can use systems thinking to effectively address complex system problems in different domains as well as who can "take a systemic persepective".[2] Holding a systemic worldview enables a higher level of thinking and leads to a dynamic decision-making process appropriate for the complex system problem domain. As Haines suggested, "systems thinking is a way of thinking whereby we see the entity or unit first as whole, within its fit and relationship to its environment as primary concerns; the parts secondary".[3]

We believe that systems thinking is a skill held at the individual practitioner level and that it is necessary for the development of understanding complex systems. This belief generated an important question that is not answered in the current body of literature: *how can an individual's* *capacity for systems thinking be identified?* Although some methods of identifying and quantifying systems thinking abilities exist, they are predominately specified for small scale problems or particular domains (i.e. education, philology). To answer our question we first conduct a broad review of systems thinking literature to identify the characteristics most commonly attributed to complex systems. The review leads to the development of a free domain systems thinking instrument that captures the individual's capacity for systems thinking to deal with complex system problem domains. The focus is on the establishment of a systemic profile at the individual level. The next section scrutinizes the systems thinking instrument and its implications. The paper concludes with recommendations and future research.

Existing Tools and Techniques

Before discussing the systems thinking instrument, we briefly review some of the existing tools and techniques used for systems thinking in educational settings. Bloom *et al.* developed a taxonomy that classifies the outcomes of students' learning process (i.e. test items).[4] Anderson and Krathwohl revised Bloom's taxonomy by suggesting more learning process objectives.[5] Along the same vein, Hopper and Stave developed an assessment framework for systems thinking intervention in educational settings based on a conceptual systems thinking taxonomy and Bloom's *et al.* taxonomy of educational objectives.[6, 7] The framework is designed for K-12 classrooms with a primary emphasis on teachers teaching systems thinking in the classroom. Frank supports the inclusion of systems thinking in curriculum stating "the capacity for engineering systems thinking can be developed in the early stages of engineering education".[8] However, he also mentioned that the literature related to studying characteristics of systems professionals is still in the early stages and notes the lack of and need for a tool for assessing systems thinking abilities.[8, 9] While this is only a small sample of the available research, all of these studies were restricted to a specific category of 'systems engineer' within specific organizations. The intention is not to criticize existing tools but rather to raise awareness of the need to develop systems thinking tools purposefully designed to deal with complex systems problem domains. While systems thinking is not presented as a universal solution, it does offer a more robust level of thinking for dealing with complexity as evidenced by the literature for systems thinking.

The Development and Outcomes of the Systems Thinking Instrument

In order to build a rigorous systems thinking instrument, first a legitimate question should be answered: *what are the main attributes that constitute a complex system?* To answer this question, Jaradat *et al.* traced the history of complex systems/system of systems in different domains from 1911- 2014 (covering more than one thousand sources) and found that there have been several perspectives, taxonomies, and definitions of complex systems.[2,10-13] Based on coding analysis research, seven main attributes were identified. These are the most dominant (most coded) attributes of complex systems across different domains:

- *Interconnectivity* – interactions between systems' parts and components
- *Integration* – multiple sub-entities combined to produce new capabilities and goals
- *Evolutionary development* – rapid changes in technology, requirements, and environment
- *Emergence* – unpredictable events and system behaviors only apparent after occurrence

- *Complexity* – dynamic interconnectivity precludes complete understanding
- *Uncertainty* - incomplete knowledge of systems leading to unintended consequences
- *Ambiguity* – lack of clarity necessary to support decisive action and commitment to alternative courses of action

In responding to these attributes, a systems thinking instrument is developed using a mixed method approach to collect qualitative and quantitative data for analysis.[2] A qualitative method using grounded theory coding, an inductive research design, was used to derive a set of systems thinking characteristics. Nvivo, software specialized for grounded theory coding, was used to navigate and manage the large amount of qualitative data produced. More than three hundred and fifty individuals participated in the research to test and validate the systems thinking instrument. The sample of the study was heterogeneous with participants from different domains including engineers, students, physicians, and others. The dataset obtained from the participants was also analyzed quantitatively using Exploratory Factor Analysis and Monte Carlo Simulation. The systems thinking instrument captures and measures the state of systems thinking at the individual level given a complex problem domain scenario. To validate the utility of the systems thinking instrument, different validity and reliability tests were conducted, including Cronbach's alpha ($\alpha = 0.87$).

The instrument consists of 39 binary questions and accompanying score sheet that provides an individual's systems thinking profile, consisting of seven letters. The systems thinking profiles (7-letters) captures an individual capacity for systems thinking, and thus their inclinations to engage complex system problems. It is essential to mention that there are no fundamentally good or bad systems thinking profiles[2]. The value of any systems thinking profile depends solely on the uniqueness of the complex system problem. Some common profiles are given as examples in Figure 1, though 49 different profiles could theoretically be realized. These different profiles position individuals as *high-holistic system thinkers, holistic system thinkers, middle system thinkers,* or *reductionist system thinkers*.

CGIYEHF High-holistic system thinker	CAIYEHF Holistic system thinker
SANVTRD Reductionist system thinker	CAIVTRD Middle system thinker

Figure 1: Examples of systems thinking profiles

As shown in Figure 2, the instrument consists of seven scales to measure fourteen major preferences. These fourteen categories reflect an individual's systems thinking capacity in dealing with complex system problems. The first pair, *level of complexity (C-S)* describes an individual's comfort zone for engaging complex system problems. The second pair, *level of autonomy (G-A)*, describes an individual's inclination in dealing with integration of multiple systems or internal systems. For instance, (G)-type systems thinkers focus more on applying a global perspective and treat the system as an integrated unit. The third pair, *level of interaction (I-N)*, describes what type of scale an individual would choose to work with. The fourth pair, *level of change (Y-V)*, indicates an individual's propensity to accept change. The fifth pair, *level of uncertainty (E-T)*, describes an individual's preference in making decisions with incomplete knowledge. The sixth pair of preferences, *level of hierarchical view of the system (H-R)*, indicates the way an individual approaches problems within a larger complex system. An individual whose answers fall into the (H)-category is probably more interested in applying big picture concepts and ideas. Conversely, (R)-type systems thinkers prefer to focus on particulars and details. The last pair of preferences, *level of flexibility (F-D)*, describes an individual's preference to altering plans. In large complex system problems where the environment is changing rapidly, a flexible type system thinker is often preferable for coping with these environmental changes (i.e. implementation of new technologies).

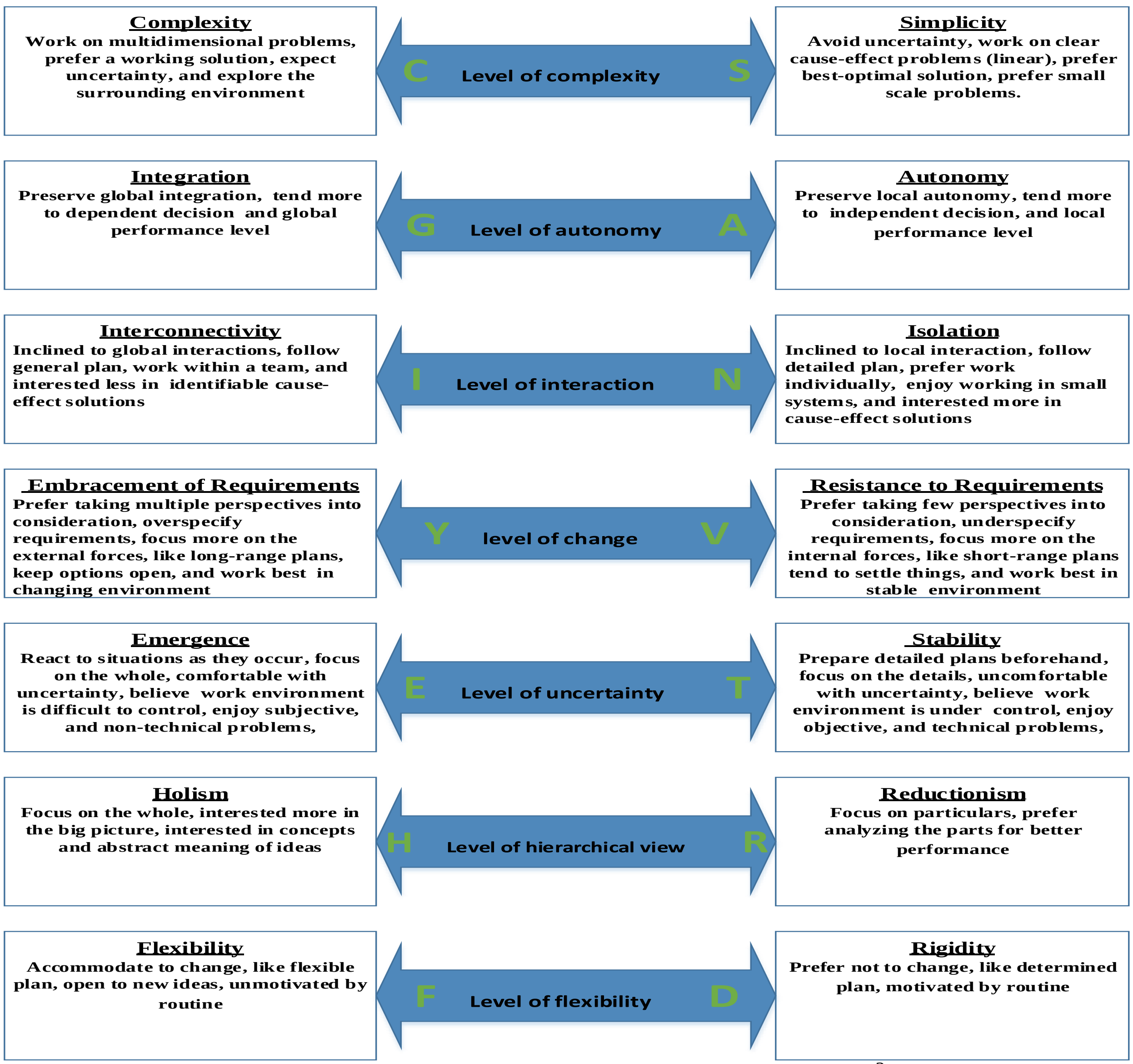

Figure 2: Systems Thinking Preferences Pairs (p. 65)[2]

Implications, Conclusions, and Future Research

These seven systems thinking preference pairs capture and determine an individual's fitness for systems thinking. Based on these preference pairs individuals can obtain their systems thinking profiles. As we discussed earlier, the suitability of the individuals' systems thinking profiles are dependent on the nature, context, and priorities of solving complex systems. For instance, individuals with higher levels of systems thinking (holistic systems thinkers) abilities will enjoy working in large-scale complex systems more than individuals who are not as strong of systems thinkers (reductionist systems thinkers). Pinto *et al.* mentioned that this does not mean that non-system thinkers will not be successful in solving complex system problems; however, the nature of these systems will present difficulties (frustration, inaccurate decisions, knowledge) due to the probable incompatibility with their worldviews.[14]

The main contribution of the instrument is 'to provide a baseline snapshot' that shows systems thinking profiles for individuals. We believe that identifying the individual level of systems thinking, indicative of an individual's propensity to engage with complex problems, has several implications across domains.

- The development and design of complex systems are executed by individuals. Providing a set of systems thinking profiles would certainly show how fit an individual is to engage in the development process of these systems.
- The determination of systems thinking capabilities for individuals can help realistically identify what is needed to design rigorous complex systems.
- This instrument enables matching individual potential with job requirements by assessing the level of systems thinking for an individual. It is important to mention that the systems thinking instrument does not measure personality preferences, rather it measures the level of systems thinking.

The systems thinking instrument is considered an intervention tool at multiple levels: professionals, students, organizations, teams, and others. It helps responsible professionals to more effectively form teams based on their systems thinking profiles and compatibility with the complexities faced in the problem domain in which they are anticipated to be deployed. In particular, we believe that the systems thinking instrument would be a good fit within STEM research areas, but further research is needed to study what should be included in STEM education from complex system, systems theory and system of systems perspectives. The principle questions that need to be answered are: *What qualifications (systems skills) should an engineer attain to be successful in the engineering domain?* and *What should be included or excluded from the curriculum to ensure systems thinking capabilities?* The application of this instrument in STEM fields would help in answering these questions and move the fields forward.

References

[1] Shareable Infographics. (2016). Top 10 skills [Infographic]. The Future of Jobs: World Economic Forum. Retrieved March 09, 2016 from http://reports.weforum.org/future-of-jobs-2016/shareable-infographics/

[2] Jaradat, R.M. (2015). Complex system governance requires systems thinking – how to find systems thinkers. *Int. J. System of Systems Engineering*, *6*(1-2), 53–70.

[3] Haines, S. G. (1998). *The Managers Pocket Guide to Systems Thinking*. Amherst, MA: HRD Press.

[4] Bloom, B.S., M.D. Engelhart, E.J. Furst, W.H. Hill, D.R. Krathwohl. (1956). *Taxonomy of Educational Objectives: Handbook I: Cognitive Domain*. New York: David McKay.

[5] Anderson, L.W., D.R. Krathwohl. (2001). *A taxonomy for learning, teaching, and assessing*. New York: Longman.

[6] Hopper, Megan, Krystyna A. Stave. (2008). Assessing the effectiveness of systems thinking interventions in the classroom." *Proceedings of the 26th International Conference of the System Dynamics Society*. Athens, Greece.

[7] Stave, K., M. Hopper. (2007). What constitutes systems thinking? A proposed taxonomy. *The 25th International Conference of the System Dynamics Society*. Boston, Massachusetts.

[8] Frank, M. (2006). Knowledge, abilities, cognitive characteristics and behavioral competences of engineers with high capacity for engineering systems thinking (CEST). *Journal of Systems Engineering*, *9*(2), 91-103.

[9] Frank, M. (2002). Characteristics of engineering systems thinking-a 3D approach for curriculum content. *IEEE Transactions on Systems, Man, and Cybernetics, Part C: Applications and Reviews*, *32*(3), 203-214.

[10] Jaradat, R., Keating, C., Bradley, J. (2014). A histogram analysis for system of systems. *Int. J. System of Systems Engineering*, *5*(3), 193–227.

[11] Boardman, J., Sauser, B. (2008). *Systems thinking: Coping with 21st century problems*. New York: CRC Press.

[12] Carlock, P. G., Fenton, R. E. (2001). System of systems (SoS) enterprise systems engineering for information-intensive organizations. *Systems Engineering Journal*, *4*(4), 242–261.

[13] Chen, P. and Clothier, J. (2003). Advancing systems engineering for systems-of-systems challenges. *Systems Engineering Journal*, *6*(3), 170–181.

[14] Pinto, C., Magpili, L., Jaradat, R. (2015). *Operational Risk Management: a systems approach*. Momentum Press, U.S.