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A Definition of Systems Thinking: A Systems Approach

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Abstract

This paper proposes a definition of systems thinking for use in a wide variety of disciplines, with particular emphasis on the development and assessment of systems thinking educational efforts. The definition was derived from a review of the systems thinking literature combined with the application of systems thinking to itself. Many different definitions of systems thinking can be found throughout the systems community, but key components of a singular definition can be distilled from the literature. This researcher considered these components both individually and holistically, then proposed a new definition of systems thinking that integrates these components as a system. The definition was tested for fidelity against a System Test and against three widely accepted system archetypes.

Systems thinking is widely believed to be critical in handling the complexity facing the world in the coming decades; however, it still resides in the educational margins. In order for this important skill to receive mainstream educational attention, a complete definition is required. Such a definition has not yet been established. This research is an attempt to rectify this deficiency by providing such a definition.

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1. Introduction

There is no denying the rapid growth of the complex systems that continuously spring to life in the world around us. As nations become increasingly interconnected, globalization grows our social systems in complex new ways. Technological advancement spawns system after system, each increasing in interdependence on other systems that have come before (Internet, GPS, power grid, software APIs, et al.). International trade ties nations together in powerful economic feedback loops. Policy changes in one nation inevitably cause ripple-effects in another. Systems, if ever they were separated, are indomitably moving towards interconnectedness as we hurtle into a globalized future. All of these systems feed into each other to produce extremely complex, unpredictable effects. Or, do they?

With the use a skill set called *systems thinking*, one can hope to better understand the deep roots of these complex behaviors in order to better predict them and, ultimately, adjust their outcomes. With the exponential growth of systems in our world comes a growing need for systems thinkers to tackle these complex problems. This need stretches far beyond the science and engineering disciplines, encompassing, in truth, every aspect of life. Now, more than ever, systems thinkers are needed to prepare for an increasingly complex, globalized, system of systems future in which everything from Canadian logging to Middle-Eastern oil drilling to Australian diamond mining will produce ripple effects throughout the globe. Based on this reasoning, it could be strongly argued that all people in decision-making roles should have a solid grasp on systems thinking.

Barry Richmond, a well-known leader in the field of systems thinking and systems dynamics, is credited with coining the term "systems thinking" in 1987. He writes (1991):

As interdependency increases, we must learn to learn in a new way. It's not good enough simply to get smarter and smarter about our particular "piece of the rock." We must have a common language and framework for sharing our specialized knowledge, expertise and experience with "local experts" from other parts of the web. We need a systems Esperanto. Only then will we be equipped to act responsibly. In short, interdependency demands Systems Thinking. Without it, the evolutionary trajectory that we've been following since we emerged from the primordial soup will become increasingly less viable.

Many researchers and systems science experts are in agreement with Richmond's views on the great importance of systems thinking in dealing with the coming century's complexity[5, 7, 11, 14]. The need to improve students' ability to understand complex systems has been documented as early as the 1950s[7]. Many educators believe that systems thinking represents an answer to this call and that the need for general public capable of understanding systems and complexity is now more pressing than ever[7]. Many more assertions like this can be found throughout the literature. If these field leaders and researchers are to be believed, it would seem that systems thinking is extremely important for our future.

2. Systems thinking

If it is so important, then what exactly *is* systems thinking? The term has been defined and redefined in many different ways since its coining by Barry Richmond in 1987. What makes systems thinking so difficult to define? Why is it constantly redefined? What is missing? Perhaps, rooted in our own field, lies the answer to defining the elusive concept of systems thinking in a way that will allow it to be measured. To this end, proposed is a surprisingly straightforward step in defining systems thinking – the application of systems thinking *to itself*.

According to the Merriam-Webster dictionary, a system is defined as a regularly interacting or interdependent group of items forming a unified whole (Merriam-Webster's online dictionary, n.d.). A basic principle of a system is that it is something more than a collection of its parts[5]. Following this line of reasoning, it immediately becomes apparent that systems thinking can be viewed *as a system*. Systems thinking is, literally, a *system of thinking about systems*. As discussed later in this paper, this highlights the problems with the definitions available in the literature. These definitions tend to analyze systems thinking through a reductionist approach – generally considered a non-systems-thinking approach. Reductionist models are unable to fully depict, or to allow us to deeply understand, new complex and dynamic scenarios[2].

As with most systems, systems thinking consists of three kinds of things: elements (in this case, characteristics), interconnections (the way these characteristics relate to and/or feed back into each other), and a function or

purpose[5]. Notably, the least obvious part of the system, its function or purpose, is often the most crucial determinant of the system's behavior[5]. Though not all systems have an obvious goal or objective, systems thinking does. In order to convey its definition, especially to those unfamiliar with the concept, it is critically important to communicate this goal.

Therefore, a requirement for a complete systems thinking definition should be that it defines the latter as a goal-oriented system. To accomplish this, the definition must contain all three of the aforementioned kinds of things (elements, interconnections, and a goal or function). To this end, the literature definitions will be examined and subjected to a System Test which will test whether or not they define systems thinking as a system.

2.1 The System Test

The System Test, shown in Figure 1, was devised as a means by which to test a systems thinking definition for systemic fidelity. The test is relatively simple. Each definition will be examined to determine if it contains these three things:
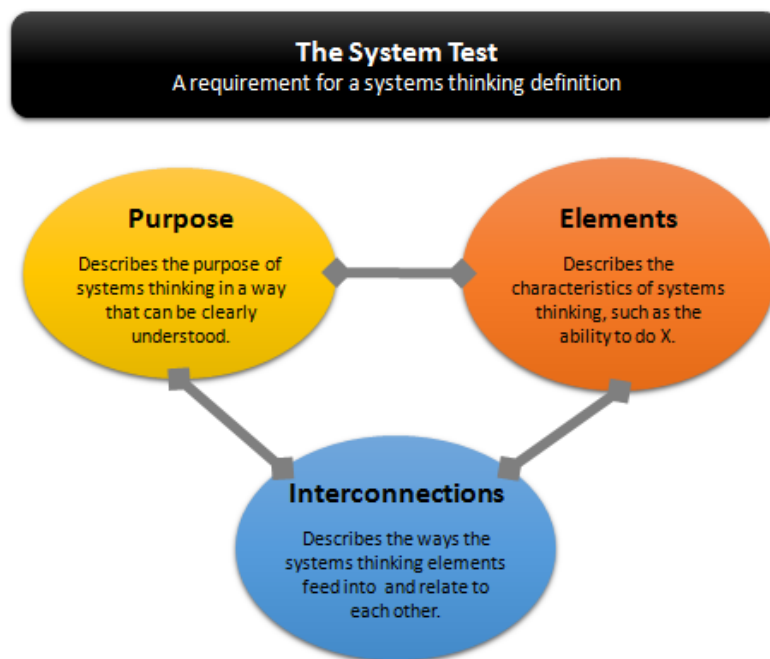

Fig. 1: The System Test

1. Function, purpose, or goal. This should describe the purpose of systems thinking in a way that can be clearly understood and relates to everyday life.
2. Elements. These elements will manifest as characteristics of systems thinking.
3. Interconnections. This is the way the elements or characteristics feed into and relate to each other.

Of course, the simple fact that a definition describes systems thinking as a system does not necessarily mean it is a correct definition. However, the System Test should be considered as a necessary, but not sufficient set of criteria for a systems thinking definition to be considered complete.

2.2 Testing the Literature Definitions

Barry Richmond's definition

Barry Richmond, the originator of the systems thinking term, defines systems thinking as the art and science of making reliable inferences about behavior by developing an increasingly deep understanding of underlying structure[10]. He emphasizes that people embracing Systems Thinking position themselves such that they can see both the forest and the trees; one eye on each[10].

This definition is board but useful, especially the notion of "seeing both the forest and the trees," but it fails number 3 of the System Test because it does not adequately explain the interconnections between the elements of systems thinking.

Peter Senge's definition

Peter Senge, another leader in the field, defines systems thinking as a discipline for seeing wholes and a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static snapshots[11]. Senge also asserts that people who succeed in handling complexity are working in an intuitive domain we don't even consider in our educational theories, underscoring an intuitive property of systems thinking[1].

Senge's definition, although interesting, is also vague. The definition does describe several highly critical elements of systems thinking, but it does not provide a purpose for systems thinking. It could be argued that this lack of purpose makes the definition difficult to understand. Also, the interconnections between elements are not specified or recognized. Therefore it does not pass the System Test. However, the way that Senge defines systems thinking by describing it as a discipline and a framework seems to evoke a certain understanding of its deeper meaning, hinting at its nature as a system.

Sweeney and Sterman's definition

Linda Sweeney and John Sterman, authors and researchers in the field of systems thinking, found that that much of the art of systems thinking involves the ability to represent and assess dynamic complexity (e.g., behavior that arises from the interaction of a system's agents over time), both textually and graphically[15]. They list specific systems thinking skills as including the ability to:

1. Understand how the behavior of a system arises from the interaction of its agents over time (i.e., dynamic complexity);
2. Discover and represent feedback processes (both positive and negative) hypothesized to underlie observed patterns of system behavior;
3. Identify stock and flow relationships;
4. Recognize delays and understand their impact;
5. Identify nonlinearities;
6. Recognize and challenge the boundaries of mental (and formal) models.

Sweeney and Sterman attempt to define systems thinking in terms of a purpose, *to represent and assess dynamic complexity*, but they don't explain what the purpose of assessing dynamic complexity is (to aid in solving systemic problems). They then break this definition down into parts. It seems that Sweeney and Sterman's high level definition can immediately be reduced to this simpler statement: *The art of systems thinking involves the ability to represent and assess dynamic complexity*. This idea is then followed by their six specific systems thinking skills.

Overall, this definition is extremely useful, as it lists actual skills agreed upon by many advocates of systems thinking[15]. However, this definition fails the System Test because it does not clearly define a purpose or goal that relates to everyday life. Also, interconnections between elements are not addressed. The definition fails to capture the overall nature of systems thinking - the parts interacting to form a whole system.

Hopper and Stave's definition

Megan Hopper and Krystyna Stave incorporated Sweeney and Sterman's work, and the work of many others, into their own study of systems thinking. Reinforcing the need for a widely accepted definition, they assert that the term systems thinking is used in a variety of sometimes conflicting ways[13]. For example, some system dynamicists see it as the foundation of system dynamics as well as a number of other systems analysis approaches; others see systems thinking as a subset of system dynamics[13]. Hopper and Stave performed an extensive review of systems dynamics literature, drawing up the following list of Systems Thinking Characteristics based on their findings[13]:

1. Recognizing Interconnections
2. Identifying Feedback
3. Understanding Dynamic Behavior
4. Differentiating types of flows and variables
5. Using Conceptual Models
6. Creating Simulation Models
7. Testing Policies

Hopper and Stave draw upon Richmond, Senge, Sweeney and Sterman in their definition, along with many others. However, their definition does not contain interconnections or a statement of purpose for systems thinking, and thus fails the System Test. Their definition is simply a set of characteristics, and not a system.

Kopainsky, Alessi, and Davidsen's definition

Building on Hopper and Stave's work, Birgit Kopainsky, Stephen M. Alessi, and Pål I. Davidsen, state that the definition of systems thinking should include appreciation for long term planning, feedback loops, non-linear relationships between variables, and collaborative planning across areas of an organization[4].

This definition adds several new characteristics to Hopper and Stave's. However, it suffers from the same problem– it does not define systems thinking as a system, only a set of characteristics. The elements are defined, but not the purpose or interconnections, thus failing the System Test.

Squires, Wade, Dominick, and Gelosh's definition

Systems thinking was defined as part of a research project to accelerate the teaching of new systems engineers[12]:

Systems thinking is the ability to think abstractly in order to:
- incorporate multiple perspectives;
- work within a space where the boundary or scope of problem or system may be "fuzzy";
- understand diverse operational contexts of the system;
- identify inter- and intrarelationships and dependencies;
- understand complex system behavior; and most important of all,
- reliably predict the impact of change to the system.

This definition works well as a description of systems thinking. However, it is oriented towards describe what systems thinking needs to do rather than actually defining it. This is quite useful but also fails the System Test, since it does not fully describe interconnections and elements of systems thinking.

Jay Forrester's definition

As a contrast to the discussion on what systems thinking is, it is important to consider one example of what systems thinking is *not*. Jay Forrester, known as the founder of System Dynamics, presents just such a definition. Even though he uses the term "systems thinking" differently, or perhaps *because* he does, his definition should be

considered in order to comprehensively discuss systems thinking. He writes (1994):

"Systems thinking" has no clear definition or usage. ... Some use systems thinking to mean the same as system dynamics. ... "Systems thinking" is coming to mean little more than thinking about systems, talking about systems, and acknowledging that systems are important. In other words, systems thinking implies a rather general and superficial awareness of systems.

The systems thinking that Jay Forrester is writing about here is *not* our systems thinking. He appears to be using the term in a different way. However, note Dr. Forrester's assertion that systems thinking has no clear definition or usage – this again reinforces the need for a complete, widely accepted definition.

Comparison of definitions

Although the literature definitions have all failed the System Test, parts of these definitions are still very useful and relevant. In ultimately defining systems thinking as a system, considering and synthesizing important parts of these definitions is key. Shown in Figure 2 is a diagrammatic comparison of the different aspects of the literature definitions discussed above.
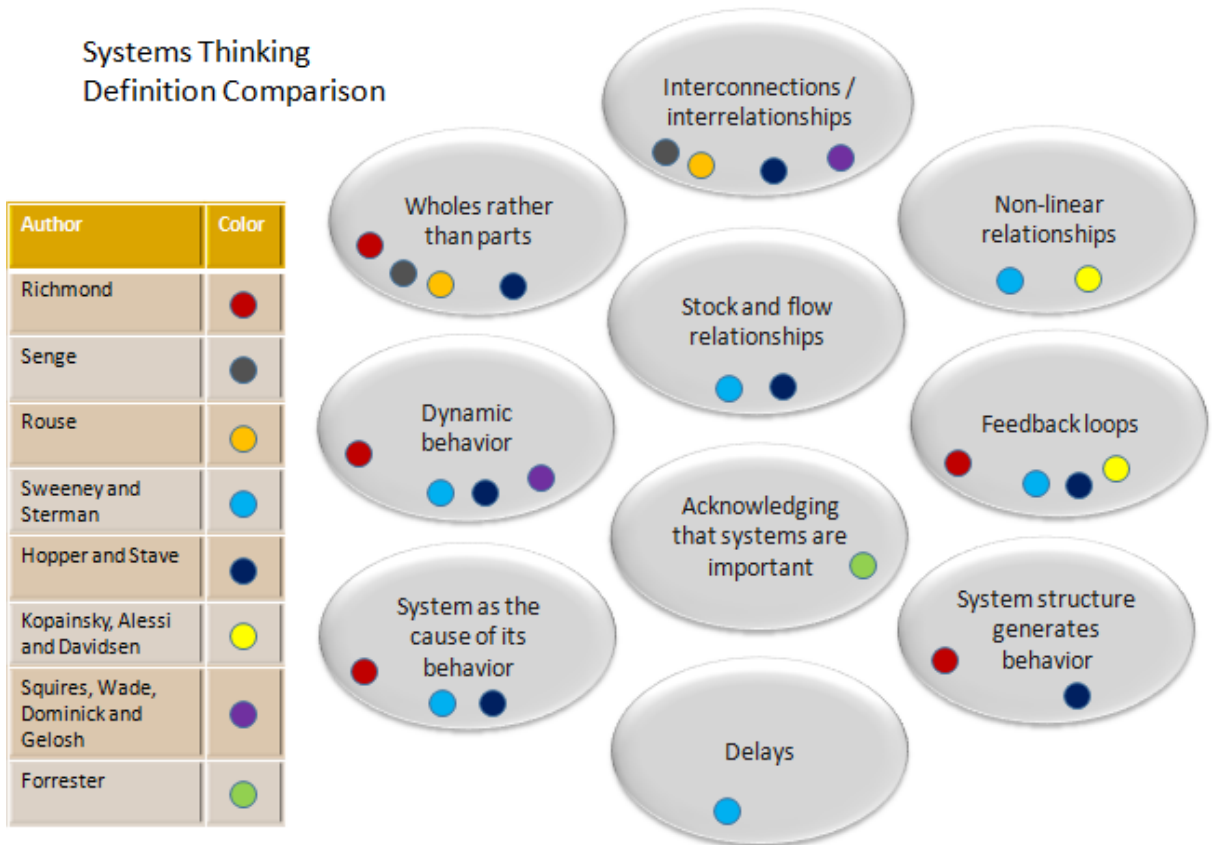

Fig. 2: Comparison of Systems Thinking Definitions

In all of these definitions, common elements tend to include interconnections, the understanding of dynamic behavior, systems structure as a cause of that behavior, and the idea of seeing systems as wholes rather than parts. This is especially true if extra consideration is given to the comprehensive literature review provided by Hopper &

Stave, which covers a vast arena of literature on the topic, and to Peter Senge and Barry Richmond, well-respected gurus in the field.

3. Definition of systems thinking as a system

As shown above, the systems thinking definitions proposed by many other authors have focused on the elements of which systems thinking is *made*, by defining its components (which has been accomplished quite thoroughly), but have neglected to detail what systems thinking *actually is,* and perhaps even more importantly, what systems thinking *does*; the "essence" of what makes the system what it is. These characteristics seem to lack some abstract but important element. This element is the *system* aspect of systems thinking. Following Richmond's principle to focus on both the forest and the trees[10], it appears that many of these definitions may have focused on either the forest or the trees. Some define systems thinking too vaguely, while others have, perhaps, simplified systems thinking *too much*. Both approaches do not capture the systemic essence of systems thinking.

Therefore, a new definition is proposed – to define systems thinking *as a system* by identifying its goal and then elaborating upon both its elements and the interconnections between these elements.

The idea of defining a system by its goal is ubiquitous and can be found in myriad systems around us – a water treatment system, a house heating system, a power system or a transportation system – these systems are all named by their purpose. Thusly, systems thinking can also be defined in terms of its purpose. Once this is done, the elements and interconnections between these elements will be elaborated further. First, the objective definition:

Systems thinking is 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. These skills work together as a system.

The elegance of this definition is in its simplicity and utility. With a bit of background on the nature of a system, this definition could be presented in an understandable way to an audience with no background in systems science.

The terms included in the definition are themselves defined as the following:

- **Systems**: *Groups or combinations of interrelated, interdependent, or interacting elements forming collective entities*.
- **Synergistic**: *Characteristic of **synergy**, which is the interaction of elements in a way that, when combined, produce a total effect that is greater than the sum of the individual elements*.
- **Analytical skills:** *Skills that provide the ability to visualize, articulate, and solve both complex and uncomplicated problems and concepts and make decisions that are sensible and based on available information. Such skills include demonstration of the ability to apply logical thinking to gathering and analyzing information, designing and testing solutions to problems, and formulating plans.*
- **Identify:** *To recognize as being a particular thing*.
- **Understand:** *To be thoroughly familiar with; apprehend clearly the character, nature, or subtleties of*.
- **Predict:** *To foretell as a deducible consequence*.
- **Devise modifications:** *To contrive, plan, or elaborate changes or adjustments*.

Now that systems thinking has been defined by its objective, the definition will be expanded in terms of its content (elements and interconnections). This content contains, in part, the synthesis of definitions taken from the literature above. The content is presented as a systemigram, shown in Figure 3.
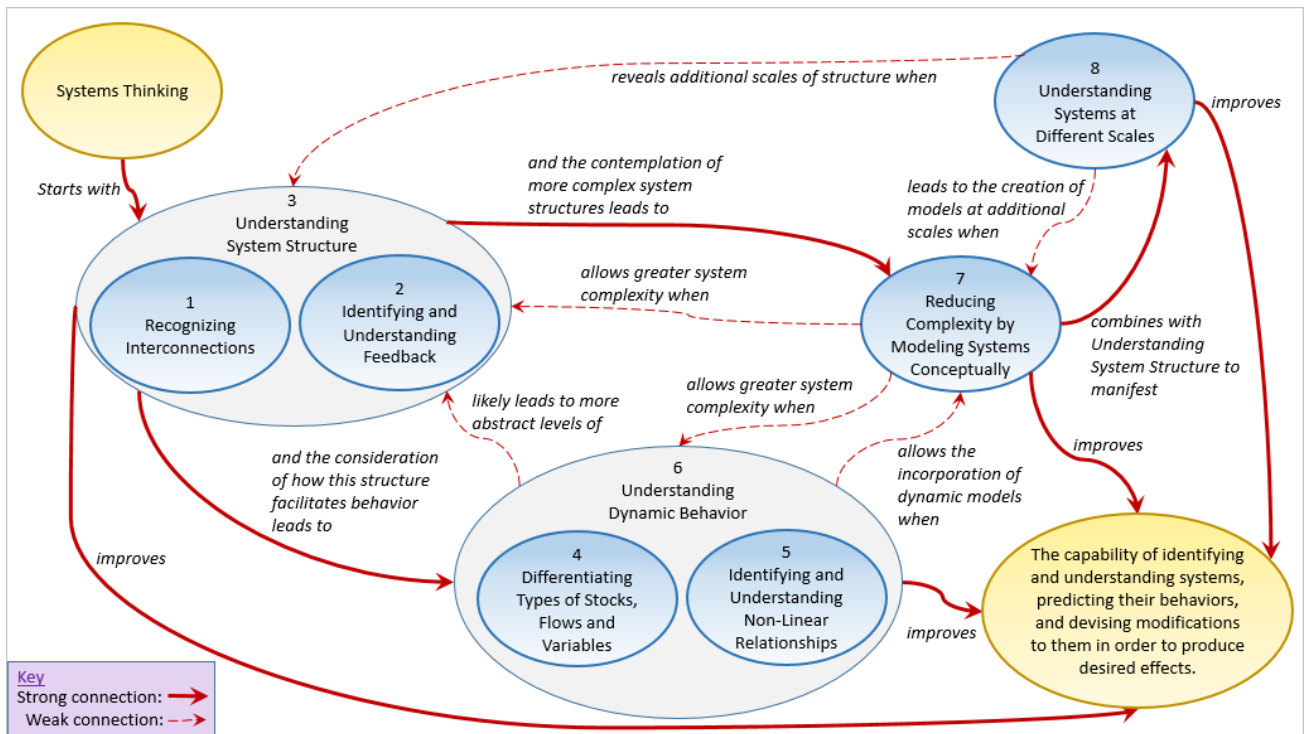
Fig 3: Systems Thinking Systemigram

In this systemigram, thick lines represent strong connections, while thin dotted lines represent weaker, but still important, connections. It is important to note that the system of Systems Thinking as depicted in this systemigram operates as a series of continuous feedback loops. That is to say, the system does not cease to function at the final node. Rather, as each of the elements improves and in turn improves connected elements, Systems Thinking itself continuously improves.

The elements presented in the systemigram are synthesized from the literature definitions, leveraged primarily from Sweeney and Sterman[15], Hopper and Stave[3], and Plate[8]. The main deviations from those two works lies in two elements: *Reducing Complexity by Modeling Systems Conceptually* and *Identifying and Understanding Non-Linear Relationships*. All of the elements are described below:

1. Recognizing Interconnections:

This is the base level of systems thinking. This skill involves the ability to identify key connections between parts of a system. Even highly educated adults without systems thinking training tend to lack this ability[8].

2. Identifying and Understanding Feedback:

Some of the interconnections combine to form cause-effect feedback loops[3]. Systems thinking requires identifying those feedback loops and understanding how they impact system behavior[8].

3. Understanding System Structure:

System structure consists of elements and interconnections between these elements. Systems thinking requires understanding this structure and how it facilitates system behavior[6, 10]. Recognizing interconnections and understanding feedback are keys to understanding system structure. Although this element is not specifically referenced in Hopper and Stave's (2008) or Plate's (2014) taxonomies, it can be implied as a combination of the two aforementioned elements and is referenced in other important works[6, 10].

4.   Differentiating Types of Stocks, Flows, Variables:

Stocks refer to any pool of a resource in a system. This could be physical, like the amount of paint in a bucket, or emotional, like the level of trust from one friend to another. *Flows* are the changes in these levels. Variables are the changeable parts of the system that affect stocks and flows, such as a flow rate or the maximum quantity of a stock. The ability to differentiate these stocks, flows, and other variables and recognize how they operate is a critical systems thinking skill.

5.   Identifying and Understanding Non-Linear Relationships:

This element represents a deviation from both Hopper and Stave's (2008) and Richard Plate's (2014) taxonomies[3, 8]. This element refers to stocks and flows of a non-linear nature. It is conceptually possible to group this element under Differentiating Types of Stocks, Flows, and Variables. However, the latter seems to imply a linear flow. To avoid confusion, non-linear flows are separated out into this element.

6.   Understanding Dynamic Behavior:

Interconnections, the way they combine into feedback loops, and the way these feedback loops influence and consist of stocks, flows and variables create *dynamic behavior* within a system. This behavior is difficult to grasp or understand without systems training[8]. *Emergent behavior,* a term used to describe unanticipated system behavior, is one example of dynamic behavior. Differentiating types of stocks, flows, and variables, as well as identifying and understanding non-linear relationships, are both keys to understanding dynamic behavior.

7.   Reducing Complexity by Modeling Systems Conceptually:

This element represents a deviation from both Hopper and Stave's (2008) and Richard Plate's (2014) taxonomies[3, 8]. Although it sounds similar to Hopper and Stave's *Using Conceptual Models*, this element is different. This element is the ability to conceptually model different parts of a system and view a system in different ways. Performing this activity extends beyond the scope of defined system models and enters the realm of intuitive simplification through various methods, such as reduction, transformation, abstraction, and homogenization[16]. Research shows that perceptual wholes can reduce the conscious accessibility of their parts[9]. This theoretically allows the interpretation of greater complexity as the mind holds less detail about each whole. This skill could also be viewed as the ability to look at a system in different ways that strip out excess and reduce complexity.

8.   Understanding Systems at Different Scales:

This skill is similar to Barry Richmond's forest thinking[8]. It involves the ability to recognize different scales of systems, and systems of systems.

Finally, the proposed definition must be subjected to the System Test. It passes Item 1 of the tests, as it contains a clearly defined, understandable, and relatable goal. It also passes Item 2: its elements are described in detail. It also passes Item 3, as interconnections and dependencies between the elements are described in the systemigram. Therefore, this definition is the first that passes the System Test and successfully defines systems thinking as a system.

4. Conclusion

The ability of our world's citizens to perform effective systems thinking is extremely important to the world's future. The use of systems thinking transcends many disciplines, supporting and connecting them in unintuitive but highly impactful ways. Thus far, the systems thinking skill set has remained on educational margins for a variety of reasons. One of these reasons is the absence of a widely accepted, complete definition of systems thinking. Proposed in this paper is such a definition. The proposed definition passes a System Test, confirming its systemic fidelity. The definition includes a clear goal, elements of systems thinking, and descriptions of interconnections between these elements. The definition synthesizes the most common and critical systems thinking

competencies discussed in the literature. Moving forward, this definition can be used for systems thinking educational efforts, systems science, and a myriad other disciplines which require the use of critical systems understanding and intuition.

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