Chapter 31
Systems Thinking

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ABSTRACT

In this chapter, we focus on systems thinking. A system is a group of interacting, interrelated, and interdependent components that form a complex and unified whole. Systems thinking is a way of understanding reality that emphasizes the relationships among a system's parts that goes beyond the parts themselves. We first provide brief professional profiles for three of the most relevant theorists: Ludwig von Bertalanffy, Peter Senge, and Donella Meallows. Secondly, we describe the primary issues of systems thinking and explain why this is an important theory. We have also included historical and theoretical background and relevant references. Thirdly, we make connections of the theory to science teaching and learning. We stated some advantages and challenges of systems thinking in relation to science education and related the theory to current teaching practices, and actual classroom applications. We have also provided examples of modeling practices, ideas, and programs. Lastly, we made references to major curricula currently in use such as the Next Generation Science Standards in the USA and 2015 PISA framework. We argue that we might need to have substantial changes in our existing science curriculum in order to encompass systems thinking and the new trends in science education like the STEM movement.
**Introduction**

This chapter was created for current and aspiring science teachers who intend to implement systems thinking in science education. We spent tremendous efforts to present the theoretical and historical background of systems thinking, a new paradigm in science education. It is expected that this chapter helps readers to understand well the practical aspects of using systems thinking in science teaching and learning contexts.

**Background**

It is merely an axiom that the world’s systems have various sorts because of their degree of complexity. One purpose of science is to provide clear descriptions, explanations, and/or predictions of behaviors of such complex phenomena in both natural sciences and social sciences.

Unfortunately, for science, only some world’s systems are static and simple ones that have foreseeable, reproducible, and reversible behaviors. The rest are with dynamic and ordered complexity. The classical scientific approach known as the analytic approach is based on reductionism for studying any science phenomenon. Reductionism sees systems as static, closed, mechanical, linear, and deterministic. However, that reflects only a small picture of the world because most of the systems include ordered complexity. They have a fluid and flow equilibrium, and they are open systems that have unforeseeable, irreproducible, and irreversible behaviors. Reductionism cannot describe how such complex systems work. Thus, an alternative view of the world uses a holistic approach that views a system as a whole and is more than the sum of the system’s parts. This approach focuses more on the interactions and relations between the system’s components. We refer to it as systems thinking; systems thinking is a universal mode of thinking, it is one form of thinking that is based on a holistic view. Systems thinking is not limited to any domain of knowledge; it integrates both analytic and synthetic approaches. In order to understand systems thinking, we first define “system”. This term “system” has been used for multi-purposes in different areas. For instance, people frequently mention communication system, education system, solar system, social system, economic system, transport system, or ecological system, and the like. The term “system” came from a Greek word σύστημα meaning “(a) whole compounded of several parts or members” (Rose, 2012, p. 9). The first use of this term was in the eighteenth century by German philosopher Immanuel Kant in the book *Critique of Pure Reason* (Reynolds & Holwell, 2010). According to Merriam-Webster's online dictionary, a system is “a regularly interacting or interdependent group of items [elements] forming a unified whole (n.d.)”. Bertalanffy defined a system “as a complex of interacting elements” (Von Bertalanffy, 1969, pp. 55-56). That means the elements are standing in interrelations. Jackson (2003) defined a system as “a complex whole where the functioning of which depends on its parts and the interactions between those parts” (Jackson, 2003, p. 3). A system can exist in any format. For example, hard systems include physical systems like river systems; soft systems include more malleable systems like biological, sociological, and economic systems.

A system usually includes three essential components: elements, interconnections, and functions or system goals (Meadows & Wright, 2008). Nonetheless, systems are perceivable objects. In some cases, we can only recognize some particular components; other components are hard to define. A system’s boundary is such an example. Different
system boundary conditions may significantly change the system behaviors. A system’s boundaries can be defined according to our view of the system itself. For example, devices (e.g., iPad, Laptop, and the like) that you are using to read an e-book (assuming you detached it from other systems, the Internet, and power) can be considered as a system. We can outline its elements, interconnections, and system functions that enable this machine to process and present the data.

Where are the boundaries of your device? Using the mechanistic system, we can sufficiently define its boundary as the device itself; the body represents the physical boundaries. In contrast, if you connect it to an electricity source, now ask yourself where is the boundary of this machine? What about these data? Where do these data come from? Consider these data as virtual elements that come from an external source; there are also other systems like the Internet through the input terminals. If someone used this device, we should also consider the Human–computer interaction (HCI). The system then includes more than one system. The boundaries are essential components in order to draw important interactions. However, deciding a system’s boundary is a significant challenge. It is difficult to imagine these innumerable series boundaries, because most of these boundaries would be worthless for many reasons. Therefore, we only try to define the best boundaries by making a decision such as extending our investigation to the individual parts. A system is usually presented in the form of models. A model is a representation of a real thing/science phenomenon. A model might have different parts/variables that are interrelated; one variable can affect other variables and might also be affected. A model as a whole highlights certain aspects of a system. Modeling is the process of designing, testing, revising/abandoning models (Zhang, Liu, & Krajcik, 2006). Meadows & Wright (2008) emphasized that one of the most troubling functions of modeling is defining the systems boundaries, especially in behavioral and social systems, as they stated:

...Systems rarely have real boundaries. Everything, as they say, is connected to everything else, and not neatly. There is no clearly determinable boundary between the sea and the land, between sociology and anthropology, between an automobile’s exhaust and your nose. There are only boundaries of words, thought, perception, and social agreement-artificial, mental-model boundaries (p.95).

If systems are not perceptible or sensible objects, how can we know the most important parts of a system? Meadows explained that by illustrating the effects of changing system components, the largest impacts come from changing systems’ functions. For instance, as Meadows illuminated, if we consider a football team as a system with parts such as players, ball, field, coach, and the like, one of its interconnections is the rules of the football game. The system goal is to win football games. If change occurred in the low level of system elements, such as changing some or even all the players, we obtain less effect on the system; we still call it a football team. Similar things happen if we look at an automobile as a system. Replacing some parts does not change the whole, it is still a car. When we move up, a change occurs at the interconnections level, we can recognize some effects. For example, if we used same elements like team players in this case, but used rules of basketball instead of those of football, we have a new game. However, the big impacts occur in changing a system’s functions or goals. For example, if we changed the purpose of the football team from winning games to losing the games, other components, such as the elements and the interconnections, remain the same, and the results might be reversed. Therefore, it is obvious that system functions are the important component of a
system; a small change in system function can cause a significant change in the whole system (Meadows & Wright, 2008).

**Systems Thinking Theories**

**Historical Background**

The beginning of the last century witnessed scientific revolutions that were not limited to modern theories in physics, such as the theory of quantum mechanics and relativity. Revolutions also extended to the science of biology. As a result of these scientific revolutions, scientists have changed their views of the world. The new contribution in biology came from Ludwig von Bertalanffy. In his General System Theory (GST), he was seeking the unity of science. He looked at the world as whole. However, the wholeness views were not new. These views have historical roots from spiritual traditions of Hinduism, Buddhism, Taoism, sufi-Islam, ancient Greek philosophy (Reynolds & Holwell, 2010) to the modern systems thinkers, such as Nicholas of Cusa, Gottfried Wilhelm Leibniz, and Johann Wolfgang von Goethe (Drack, Apfalter, & Pouvreau, 2007). These individuals, along with others who came later, influenced GST.

We start this section by repeating one famous quotation that describes systems thinking. Churchman said “A systems approach begins when first you see the world through the eyes of another” (Churchman 1968, p. 231, as cited in Reynolds & Holwell, 2010). The term of systems thinking is still new. It was coined by Barry Richmond in 1986. After much thought, Richmond came up with the term ‘systems thinking’ that is nested in the old term “structural thinking”, when he was preparing his first user's guide for his software STELLA (Structural Thinking, Experiential Learning Laboratory with Animation) (Richmond, 1994). In this instance, “systems” in plural seems to indicate the nested nature of thinking. Systems thinking is a holistic paradigm that assist in understanding complex phenomena. Complex problems tend to be linked to different problems, and seldom exist individually out of the same context. Peter Senge defined systems thinking as “a discipline for seeing wholes, as a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static” (Senge, 1990, p.68). Systems thinking can help link pieces together in order to see the big picture that might lead to understanding the situation, despite its complexity. Barry Richmond considered systems thinking “as the art and science of making reliable inferences about behaviors by developing an increasingly deep understanding of underlying structure” (Richmond, 1994).

**Ludwig von Bertalanffy and the system theory.**

Karl Ludwig von Bertalanffy was born on 19 September 1901 to a Catholic family. The roots of his family date back to the nobility of Hungary during the 16th century. General Systems Theory (GST) was formulated in the 1920s when Bertalanffy attempted to explain the functioning of biological living systems. Bertalanffy grounded GST based on the wholeness or Gestalt. The wholeness in GST referred not only to the sum of its parts, but also extended to the parts’ relations (Drack et al., 2007).

Bertalanffy first recognized living organisms as open systems. He called a system “closed” if no materials entered or left. The system is “open” if there were import and export of materials” (1969). Having empirical knowledge in related disciplines like biology, or physics, Bertalanffy built his theoretical model of open systems with "steady
states”, "dynamic equilibrium”, "equifinality", and the like. He outlined the set of mathematical equations that articulated the relationships. A system is capable of maintaining itself and constantly exchanging matter and [energy] with a surrounded environment (Von Bertalanffy, 1969). This new thought was a revolution because it sought the unification of science. This interdisciplinary perspective produced a new kind of scientific knowledge. It shifted the classical view from steady systems to dynamic systems, from isolation to openness, from traditional linear thinking that focused on the parts, to seeing the whole. In his book (Von Bertalanffy, 1969), Bertalanffy described the aims for his GST:

1. There is a general tendency toward integration in the various sciences, natural and social.
2. Such integration seems to be centered in a general theory of systems.
3. Such theory may be an important means for aiming at exact theory in the nonphysical fields of science.
4. Developing unifying principles running “vertically” through the universe of the individual sciences, this theory brings us nearer the goal of the unity of science.
5. This can lead to a much-needed integration in scientific education. (Von Bertalanffy, 1969, p. 38)

We can summarize the core ideas of system theory as follows:

- System Theory seeks the laws of unity among diverse phenomena; it aims to find the common aspects instead of focusing on a single system. A system’s entities represent the whole of natural, behavioral, or social phenomena, but the whole is more than the sum of the entities, it included the interrelations among them.
- According to Bertalanffy, the biological, behavioral, and social systems are essentially open systems that can be divided into small closed/open systems with respect to the connection with the surrounding environment.
- Any open system with its environment constantly exchange substance, energy, or even information as the input and output through a living communication channel; the channel can decrease noise to a higher degree than another lifeless communication channel (Von Bertalanffy, 1969, p. 98)
- In the open systems model, the system is dynamic over time. Along with system’s life-cycle, it is constantly involved in building up and breaking down as self-renewing processes (Von Bertalanffy, 1969, p. 39); such self-maintenance process drives the system toward higher heterogeneity and organization (Von Bertalanffy, 1969, p. 143)
- The boundary’s function is to outline the system from its surrounding environment and any other subsystems of the entire system as a whole.
- The feedback plays essential role in leading the system actions, and behaviors towards its goals.

Peter Senge and the theory of systems thinking

Senge was born in 1947. At Stanford University, he studied both engineering and philosophy. In 1970, he received his first degree from Stanford University in Aerospace engineering. Two years later at Massachusetts Institute of Technology (MIT), Senge finished his Master degree in social systems modeling. Then he continued working with Jay Forrester as a researcher at MIT until he earned his Ph.D. degree in management in 1978. His dissertation focused on “a comparison between aspects of economic modeling
through the System Dynamics National Model”. After graduation, he started his career as a lecturer at MIT Sloan School of Management (Ramage & Shipp, 2009).

In the 1950s, a massive movement in systems theory occurred when Peter Michael Senge, one of the systems thinking leaders, illustrated systems thinking language using system dynamics that was founded by Jay W. Forrester.

Senge named systems thinking as “The Fifth Discipline” in his book. He clearly described how organizations could learn, and how systems thinking could accelerate this learning. Of course, systems thinking in this learning process was not alone, there were four other disciplines: “personal mastery, mental models, shared vision, and team learning” (Ramage & Shipp, 2009). Systems thinking was integrated in each of them. They synergistically worked together. For example, systems thinking and mental models both were necessary for each other, one helped us discover and test covert assumptions and the other one guided us to reorganize those assumptions to unearth causes that shaped complex problems (Senge, 1990). Systems thinking is necessary not only to recognize the salient variables but also to discover time delays and critical feedback relations. Without systems thinking, “most of our mental models are systematically flawed” (Senge, 1990, p. 188).

In this sub-section, we have tried to enumerate rather than illuminate some Senge contributions. One contribution was elucidating the language of systems thinking as particular rules that control systems diagrams, such as systems archetype and feedback structures. Senge’s systems archetypes are used to observe, explain, and predict the complex events. All systems archetypes in the Fifth Discipline or in other literature “Systems Archetypes as Structural Pattern Templates,” seek to shift one’s mental model (mindset) to systematic thinking. Another important contribution by Senge is explaining systems thinking laws, (refer to his book The Fifth Discipline (Chapter 4), or Chapter 12-part 2 in Ramage & Shipp (2009).

Donella Meadows and the theory of systems thinking

Donella H. Meadows was born on 13 March 1941 in Illinois, USA. Dr. Donella H. Meadows is well known as a systems analysis, organic gardener, dairy farmer, a worship riser, syndicated journalists, and/or eco village developer. She started her career as a scientist. She received her B.A. in chemistry from Carleton College in 1963. She received her Ph.D. in Biophysics in 1968 from Harvard University (Ramage & Shipp, 2009). She then joined an international system dynamic team with Jay Forrester at MIT. Donella employed the tools of system dynamics, like computer modeling, to deliberate global problems such as the relationship between population, economic growth, and the earth resources. She used the concepts of feedback loops and stocks and flows to construct a detailed analysis of Leverage Points.

Donella recognized herself as a systems thinker, working with dynamic systems tools. Both Donella and Senge agreed with Jay Forrester that systems thinking did not necessarily give you the best viewpoint. It could just give you a unique view of the phenomena like other thinking paradigms. It shows some events and patterns that reflect the behaviors and complex relationships behind this order. Donella said “like any viewpoint, like the top of any hill you climb, it lets you see some things you would never have noticed from any other place, and it blocks the view of other things” (Meadows, Meadows, Randers, J., Behrens, 1972, p. 2).
Systems Thinking and Its Relation to Science Teaching

In this section we are going to diagnose the current situation of science education, and then provide a simple guide for science teachers and practitioners for implementing systems thinking in science education. We will provide some real examples supported by scientific research. Finally, we discuss the advantages and challenges of using this approach in science education.

Why is systems thinking important in science education?

One of the goals of science education is preparing our students for future challenges by enhancing their capacity of solving problems. In the late 20th Century, science education experts realized one of the most important issues facing educational systems was using reductionism and mechanistic thinking. The world is made of systems with nonlinearity; decentered control is chronic in world complex systems. Traditional science curricula deliberately simplify and reduce complexity of nature that are strongly interconnected (Forrester, 1993).

Current science curricula deal with many topics superficially, using linear and analytic methods to simplify complex systems. Students study fragments of knowledge about any natural problem in different science subjects at different grades. They may not help students form broad pictures of any phenomena. Most science curricula are not able to develop a systems foundation for problem-solving. For example, global warming has been reported in many studies. Peter Senge clearly supported this dilemma in science education. He states:

“From a very early age, we are taught to break apart problems, to fragment the world. This apparently makes complex tasks and subjects more manageable, but we pay a hidden, enormous price. We can no longer see the consequences of our actions; we lose our intrinsic sense of connection to a larger whole.” (Senge, 1990, p.1)

Natural problems may relate to different subjects (physics, chemistry, biology, and the like) at the same time. The conventional approach usually separates science into separate domains (e.g. physics, biology, chemistry). Jay Forrester addressed this issue in many situations. Although the behaviors and events of various natural phenomena are controlled by the same natural laws, current science curricula ignore this fact and offer science in a fragmented form like physics, biology, and chemistry, which appear to be innately separated from one another (Forrester, 1993). Bertalanffy had also criticized traditional education. He commented that the demand of science education was training science learners to become "scientific generalists” in the field (Von Bertalanffy, 1969). According to Senge (1990), research has shown that many young children acquired thinking skills very quickly. This indicates that students have innate systems thinking skills. However, instead of developing these skills, traditional education suppresses them by using mechanical or linear thinking.

Therefore, a shift from mechanistic to holistic or systems thinking is urgently needed. Science instructors should shift their roles to be knowledge facilitators rather than being knowledge transmitters. Students should be involved in cooperative and competitive group work, and use non-routine problem-solving and non-linear thinking. Integrating systems thinking in science learning can help students recognize the interdependence of natural and social phenomena, uncover patterns, and build concepts of systems that help...
them to obtain better understandings of complex world problems. Fortunately, there has been consensus and significant movement to bring systems thinking into K-16 curricula in the U.S. and elsewhere under an umbrella of STEM (Science, Technology, Engineering, and Mathematics) education (e.g. Duschl & Bismarck, 2016). With the rapid growth in the capabilities of computers and mobile devices, integrating simulation and modeling to study complex systems has become more available. Over the decade, there have been many efforts to integrate systems thinking tools in science learning (Jacobson, Kim, Pathak, & Zhang, 2013; Zhang, Liu, & Krajcik, 2006). Still, there are challenges to teaching science in this new way and requires paradigm change and likely overhaul of the current school and university curricula.

**Systems thinking in science curricular standards**

Systems thinking is essential to any learning organization. Pioneer science educators realized the importance of integrating systems thinking concepts, skills, and tools in science standards. The first attempt began in the 1960s. The Science Curriculum Improvement Study (SCIS) developed some science curriculum units in elementary school level that included some of the systems thinking concepts such as system, subsystems, interactions, and variables (Chen & Stroup, 1993). There are also current attempts to incorporate systems thinking into the science curricula. We will limit ourselves to examples of some initiatives that include systems thinking concepts from the Next Generation Science Standards (NGSS) for K-12 science education in U.S. We make such a decision because such a move in the U.S. has been influential. NGSS made a major revision by integrating systems thinking skills to include ‘Science and Engineering Practices (SEPs)’ and ‘Crosscutting Concepts (Ccs). Those recommendations aim to achieve systems thinking skills in science. More explicitly, the framework of crosscutting concepts includes “patterns; cause and effect; scale, proportion, and quantity; systems and system models; energy and matter; structure and function; stability and change” (NGSS Lead States, 2013, p. 79).

The framework begins in kindergarten. NGSS emphasized that students must know how to better identify issues, recognize patterns, and develop understanding of the natural phenomena around them. For example, in (K-ESS2-1) about the Earth’s systems, students should think systematically and conduct some quantitative and qualitative observations of the local weather to “describe patterns over time”. In crosscutting concepts, the world’s systems are combined from parts that work together, patterns are observable, and they can be used as evidences to explain natural phenomena (NGSS Lead States, 2013). Similarly, in (K-ESS3-1) about Earth and human activity, students should use their prior knowledge to develop a model “to represent the relationship between the needs of different plants or animals (including humans) and the places they live” (NGSS Lead States, 2013, p. 8). They should also “use a model to represent relationships in the natural world”.

Another example is from middle school in “From Molecules to Organisms” (MS-LS1-3); students should develop “basic understanding of the interaction of sub-systems within a system and the normal functioning of those systems (e.g., “the role of cells in body systems and how those systems work to support the life functions of the organism” (NGSS Lead States, 2013). In the same way, system thinking concepts clearly appeared in (MS-LS2-3.) as science learners are expected to understand the interdependences in ecosystems, matter’s cycles and energy exchange among living and
non-living parts of an ecosystem. Students are also expected to be able to define the system’s boundaries (NGSS Lead States, 2013, p. 65, 70).

Similarly, high school students in Earth and human activity (HS-ESS3-3) should be able to use computational simulation to demonstrate the relations among factors that influence the controlling of natural factors that impact on the sustainability of human populations, and biodiversity. In (HS-ESS3-6), students should use a computer model to illuminate the relationships among earth systems like (hydrosphere, atmosphere, cryosphere, geosphere, and/or biosphere) and how the human activities impact those relationships (NGSS Lead States, 2013, p.125). We applaud this effort as it will influence science education internationally. Similar efforts have also been demonstrated in some international comparative studies such as PISA (Program for International Student Assessment). The PISA framework “uses the term ‘systems’ instead of ‘sciences’ in the descriptors of content knowledge. The intention is to convey the idea that citizens have to understand concepts from the physical and life sciences, and earth and space sciences, and how they apply in contexts where the elements of knowledge are interdependent or interdisciplinary. Things viewed as subsystems at one scale may be viewed as whole systems at a smaller scale (OECD, 2016, p. 27).

Developing and assessing systems thinking skills

In order to implement science standards and facilitate the systems thinking in science education, science instructors should use well-suited methods to assist science learners to obtain and develop the essential systems thinking skills. There are different concepts in systems thinking, for example, the ability to identify patterns, actions, and recognize circular cause-effect relations (Sweeney & Sterman, 2000). Based on their literature review, Assaraf, Dodick, & Tripto (2013) classified systems thinking skills into eight hierarchical characteristics or abilities at three sequential levels as follows: (p. 36).

1. Identifying the components and processes of a system (level A).
2. Identifying simple relationships among a system’s components (level B).
3. Identifying dynamic relationships within a system (level B).
4. Organizing systems’ components, their processes, and their interactions, within a framework of relationships (level B).
5. Identifying matter and energy cycles within a system (level B).
6. Recognizing hidden dimensions of a system (i.e. understanding phenomena through patterns and interrelationships not readily seen) (level C).
7. Making generalizations about a system (level C).
8. Thinking temporally (i.e. employing retrospection and prediction) (level C).

The three levels are:
- Level A (analyzing, ability: 1)
- Level B (synthesizing, abilities: 2, 3, 4, and 5)
- Level C (implementation, abilities: 6, 7, and 8)

This hierarchical model facilitates the teaching and assessment of systems thinking skills. The degree of difficulty of systems thinking skills are ranked on a continuum from easiest to the most difficult. Lower level skills must be acquired first in order to master the highest level skills (Assaraf, Dodick, & Tripto, 2013; Rose, 2012, p. 19). Another effort that should not be ignored is a comprehensive set of systems thinking skills by Arnold & Wade (2017) that can be used either to develop or to assess system thinking competencies.
This contribution should increase the reliability and the accuracy of assessing systems thinking skills for different disciplines.

**Tools for Systems thinking**

Systems thinking is considered an advanced complex cognitive skill in which science learners have to be involved in higher order cognitive processes (Hung, 2008). Systems thinking advocates suggest some tools that might help learners to develop systems thinking skills. Among the suggested tools are systems modeling and simulations that help science learners “to simulate the behavior of systems that are too complex for conventional mathematics, verbal descriptions, or graphical methods” (Forrester, 1993, p. 185). Monat & Gannon (2015) listed some of these tools as follows:

1. Systems Archetype
2. Behavior Over Time Graphs (BOT)
3. Causal Loops Diagrams with Feedback and Delays
4. Systemigrams
5. Stock and Flow Diagrams (including Main Chain Infrastructures)
6. System Dynamics/Computer Modeling
7. Systemic Root Cause Analysis (RCA)
8. Interpretive Structural Modeling (ISM) (pp. 21-24)

These tools support different tasks. For example, “behavior over time graphs (BOT) were used at the beginning to understand system behaviors,” (Monat & Gannon, 2015, p. 21) Causal loops diagrams were used after BOT to outline the interrelationships among system’s parts. Systemic diagrams were used “to translate a system problem (expressed as structured text) into a storyboard-type diagram describing the system’s principal concepts, actors, events, patterns, and processes”. Systemic Root Cause Analysis (RCA) “is a set of problem-solving methods that help to find a fault's first or root cause” (Monat & Gannon, 2015, pp. 21-24). Regarding modeling and simulation, as stated above, sophisticated computers are able to run and solve many complex simulations. In the past, science educators used different systems tools like STELLA, Model-It, ThinkerTools, and some agent-based models programmed by NetLogo or StarLogo. Presently, more user-friendly interfaces including web-based simulations such as the PhET Interactive simulation (website: https://phet.colorado.edu/) provides a wide range of tools for science learners, without any prerequisites. Using these tools supports the development of systems thinking. It would still be necessary for students to have additional basic scientific skills, such as basic mathematics. Students should be able to collect and interpret data, as well as draw and explain data graphs (Sweeney & Sterman, 2000).

Interestingly, some findings assert that after practicing systems thinking skills learners could develop some systems thinking habits that encompass multiple thinking strategies. Sweeney and Waters Foundation labeled systems thinking habits. For more examples, refer to the suggested Resources/websites section.

**Examples linking theory and practice**

Many studies have emphasized the significance of importing systems thinking approach into education. Using systems thinking in science learning could help science learners connect their acquired knowledge. It could also increase student understanding of
interdependence between systems. Systems thinking could enhance learners’ awareness toward unifying science disciplines.

To end this section, it is necessary to present some of the recent efforts inspired by the work of Forrester and Meadows on system dynamics (Rose, 2012). For example, to implement NGSS in the real setting, NASA established The GLOBE Program, an international science and education program. GLOBE aims to provide students and the public worldwide with the opportunities to participate in data collection and the scientific process. The significance of this project is in linking worldwide science educators, researchers, students, scientists, workers, and citizens to participate in data collection and the scientific process, and develop student’s scientific understanding of the Earth system and global environment. See the GLOBE website.

Similarly, the Waters Foundation project “Systems Thinking in Schools” facilitated schools in Arizona to integrate systems thinking into their education programs. For example, Borton Primary Magnet School implemented systems thinking as a teaching method. Pima County Schools achieved content standards and skills by utilizing systems thinking (Graefe, 2010). Orange Grove Middle School integrated system thinking in their science curriculum “since the fall of 1988 in a program called Directed Learning” (Rose 2012, p. 25).

Some European schools implemented systems thinking in elementary schools. For example, in Switzerland, the Pedagogical University of St. Gallen (PHSG) was involved in developing student systems thinking. Systemdenken is a German word meaning “systems thinking”. A handbook was developed for elementary and middle school teachers to develop systems thinking competencies using action-oriented activities (see http://www.iue.ch/publikationen/systemdenken-foerdern).

We have certainly seen some of the advantages of integrating systems thinking in science education. However, serious challenges remain.

**Challenges of integrating systems thinking in science education**

The implementation of systems thinking in science education presents challenges to systems practitioners. These challenges are faced by both teachers and students. Science teachers’ understanding of systems thinking is a barrier. They should know “how to effectively facilitate students’ systems thinking” (Hogan & Weathers, 2003). Science teachers need to shift their role from being the source of knowledge to learning facilitators. Yet, there is a need for empirical research concerning teacher professional development programs for systems thinking. Students have difficulties in imperceptible causal relationships. Due to its inherent complexity and nonlinearity, systems thinking requires some higher order cognition abilities. Systems scaffolding is strongly recommended in order to overcome this challenge (Assaraf, Dodick, & Tripto, 2013).

**Summary**

Systems thinking is a universal mode of thinking. From a holistic viewpoint, systems thinking has its significance in different disciplines. Systems thinking has also been incorporated into scientists’ and engineers’ work. Systems thinking has been the underpinning of various scientific breakthroughs and offers many powerful, interactive tools to aid students to systematize, analyze, synthesize, and visualize the data to
understand complex systems. Thus, people can use it differently in their daily life to solve the problems, and to understand how the world works.

To think systematically requires knowing about (a) system (e.g., the conceptual knowledge means understanding of the essential elements, cause-and-effect relationships among systems parts, discovering patterns, and interdependences between systems); (b) modeling systems behaviors in different ways (e.g., using systems thinking tools) (Meadows & Wright, 2008; Senge, 1990); (c) systems laws; and (d) learning disabilities (Senge, 1990). In addition, implementing systems thinking has some benefits in the K–12 education context, such as, (1) helping science instructor to drive the learning process toward learner-centered approach; (2) Increasing students’ engagement; (3) providing learners more relevant experiences that lead to more effective learning; (4) improving problem solving skills (Graefe, 2010); (5) changing teachers’ and students’ perspectives about the world; (6) facilitating learning by following basic system’s rules; (7) increasing learners’ collaboration and team working; sharing thoughts and solutions of the complex problem; (8) facilitating and designing solutions, creating strategies, solving problems, while keeping the outcome / vision in mind at all times (Haines 1998). We call for more attention, research, and exploration in implementing systems thinking in K-12 and higher education in order to develop students for the 21st century.

Recommended Resources

Books

Journals
2. Systems Research And Behavioral Science: Edited By: M. C. Jackson OBE; Impact Factor: 1.034; Online ISSN:1099-1743 (http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1099-1743a)
**Websites**

1. A repository of 800+ articles on various dimensions of Systems Thinking over the past 20+ years [https://thesystemsthinker.com/](https://thesystemsthinker.com/)
2. The Bertalanffy Center for the Study of Systems Science (BCSSS) is an internationally Austrian independent research institute [http://www.bcsss.org/](http://www.bcsss.org/)
5. The Global Learning and Observations to Benefit the Environment (GLOBE) [https://www.globe.gov/about/overview](https://www.globe.gov/about/overview)
6. Linda Sweeney websites, which mixing complex systems theory, systems mapping, storytelling. [http://www.lindaboothsweeney.net](http://www.lindaboothsweeney.net); Systems thinker habits: [http://www.lindaboothsweeney.net/thinking/habits](http://www.lindaboothsweeney.net/thinking/habits)
9. The Way of Systems is a good website for introducing systems thinking concepts, tools...etc. [http://www.systems-thinking.org](http://www.systems-thinking.org)
10. Collected videos for various dimensions of Systems Thinking [https://www.youtube.com/systemswiki](https://www.youtube.com/systemswiki)
11. Society for Organizational Learning (SoL) [http://www.solonline.org/](http://www.solonline.org/)

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