systems

MDPI

Review

# Complexity Theory: An Overview with Potential Applications for the Social Sciences

**John R. Turner** and **Rose M. Baker** *

Department of Learning Technologies, University of North Texas, 3940 N Elm St, G150, Denton, TX 76207, USA; John.Turner@unt.edu

* Correspondence: Rose.Baker@unt.edu; Tel.: +1-940-369-7684

Received: 22 December 2018; Accepted: 15 January 2019; Published: 19 January 2019

**Abstract:** Systems theory has been challenged in the recent literature due to its perceived disconnection from today's research and practice demands. Moving away from the reductionist frameworks and the complicated domain predominated by known unknowns and order, a call is being made to the social sciences to begin adopting complexity theory and newer connectionist methods that better address complexity and open social systems. Scholars and scholar-practitioners will continue to find the need to apply complexity theory as wicked problems become more prevalent in the social sciences. This paper differentiates between general systems theory (GST) and complexity theory, as well as identifies advantages for the social sciences in incorporating complexity theory as a formal theory. Complexity theory is expanded upon and identified as providing a new perspective and a new method of theorizing that can be practiced by disciplines within the social sciences. These additions could better position the social sciences to address the complexity associated with advancing technology, globalization, intricate markets, cultural change, and the myriad of challenges and opportunities to come.

**Keywords:** general systems theory; complexity theory; complex adaptive systems

## 1. Introduction

The implementation of new technological innovations in the workplace and globalization are just two indicators of future, higher skilled workforce requirements [1] and herald the intensification of complexity in the workplace due to an increasing rate of unpredictable change [2], information overload, globalization, and geopolitical unrest. Organizations need to manage this growing complexity with the human resources available to them, skilled or unskilled, through the adoption and diffusion of complexity science. Becoming more prevalent across multiple disciplines as one means of making sense and being able to manage such complexity, complexity science is often recognized as the "new science" [3] (p. 94), in which organizations are viewed as complex systems that cannot be observed using traditional linear methodologies.

deMattos, Miller, and Park [4] described three trends that are contributing to the growth of complexity science. First, dramatic changes are taking place for both organizations and governments in part due to "globalization, intensive local and global competition, process re-engineering, workforce diversity, quality improvement, and continual innovation" [4] (p. 1554). Second, we are in an information revolution; the productivity of information processes is increasing, and costs are declining (e.g., information retrieval, processing, and storage). Third, organizations are dissolving at alarming rates [4].

Criticized by some because many of the existing project management tools and methodologies are reductionistic and more suited to single projects than multi-projects [5], a call for new techniques and methodologies for multi-project management efforts has been made. Given that multi-projects dominate project management, with some data estimating that multi-projects constitute as high as 90%

of projects, Aritua et al. [5] have challenged the discipline of project management to draw on research from complex, dynamical systems and from complexity theory to gain new insights into developing new techniques and methodologies. Similarly, other disciplines have been called to take the ecosystem approach, as in Gregory, Atkins, Burdon, and Elliott's [6] study on marine management. The ecosystem approach utilizes complex science by calling for a shift from reductionistic research (e.g., single-species research), compartmentalized decision making, and policy formulation to one that recognizes complex systems with multiple elements (e.g., ecological, social, economic, and political) [6].

Traditional sciences have utilized a reductionistic framework or a realist philosophy [7], in which an entity is reduced to its smaller parts. By understanding the workings of the smaller parts, the whole can be understood more comprehensively [4]. Although this reductionistic framework has served science well in the past, such as during the Industrial Revolution [4], it is inadequate to serve science well today due to the complexities of the modern world (e.g., increasing wicked problems, global warming, information overload, globalization, and geopolitical unrest). Complexity science expands on the reductionistic framework by not only understanding the parts that contribute to the whole but by understanding how each part interacts with all the other parts and emerges into a new entity, thus having a more comprehensive and complete understanding of the whole. Individual causal research in complex systems is near futile; a comprehensive approach is required to account for the unpredictability found in complex systems [7]. New theoretical models that reflect "real-life complexity" are being called for by researchers [8] (p. 162). To better understand such systems, complexity science offers complex adaptive systems (CAS) as "a framework for understanding these systems" [4] (p. 1550).

Although there is a semi-clear distinction between systems theory, complex adaptive systems, and complexity theory, the literature within some of the human resource (HR) disciplines (human relations; human resource development, HRD; and human resource management, HRM) fail to make this distinction. Today, for example, HRD still identifies systems theory as one of its foundational theories even after many disciplines have shifted to complexity theory via complex adaptive systems due to the changing and complex environment in which they operate. Disciplines have been forced to address open systems and more complex problems (e.g., wicked problems) as opposed to employing the traditional reductionistic methods used last century. Comparably, highlighted within HR and other social science literatures, systems theory has been identified as more of a myth than a foundational theory, partly due to its disconnect between practice and theory and to its overwhelming use of linear methods when examining social systems [9].

The current article identifies the differences between general systems theory (GST), complex adaptive systems, and complexity theory. It begins with a short discussion differentiating between system and systems, followed an explanation of what GST involves. Then, a clarification of open and closed systems is presented along with a discussion identifying the basic principles of complex adaptive systems (CAS) and complexity theory. The article then provides some current examples of the use of complexity theory and concludes with new directions for disciplines in the social sciences, recommending the inclusion of complexity theory in future research efforts. In the concluding remarks, the authors argue for incorporating complexity theory along with more non-reductionistic methods into the study of relationships and understanding in the social sciences in addition to the traditional GST and reductionistic methods. Also, the current article expands upon the work presented by Haslberger [8] in describing complexity theory as a new potential method for explanation and theorizing. We propose the same in the current article—that complexity theory be adopted as a new method of explanation and theorizing for the social sciences.

## 2. Systems and Complexity Theories

### *2.1. System versus Systems*

In identifying the key concepts of GST, Kast and Rosenzweig [10] (p. 450) defined a system as being "composed of interrelated parts or elements." von Bertalanffy [11] (p. 416) defined a system as a "*model* of general nature, that is, a conceptual analog of certain rather universal traits of observed entities." Perhaps the most related definition of a system is that it represents a whole consisting of several parts/members [12]. This definition hits on the distinction between a system and systems: whereas the former represents the whole (the system), the latter makes up the whole (components, systems, and subsystems). A system's components are also dependent on other components [12].

When dealing with systems, researchers need to clearly identify which level they are analyzing. Kast and Rosenzweig [10] (p. 455) stressed identifying both "the boundaries of the system under consideration and the level of . . . analysis [systems]." These boundaries vary and are typically set by the researcher or the theoretical system. Once the boundary and appropriate level of analysis (system, systems, subsystems) have been identified, the system's structure can be modeled, providing what von Bertalanffy [11] termed an *explanation in principle*. This explanation in principle provides both a level of explanation and prediction, as well as leads to the formation of systems thinking.

### *2.2. General Systems Theory*

Systems theory has been portrayed in the HR literature as transforming inputs into outputs [13] and as a method of identifying inputs, processes, outputs, and feedback components of a system to discuss and research systems more intelligently [14]. Here, systems theory has been defined as "a theoretical framework by which elements that act in concert to produce some result are studied" [9] (p. 56). In other literature, systems theory, or general systems theory (GST), has been defined as "an openness of social systems, but also implies system boundaries and stable patterns of relationships within boundaries" [15] (p. 352). By identifying boundaries between systems and their environment, researchers are better able to study interactions between the systems and their environment [16]. Koopmans [17] (p. 21) highlighted von Bertalanffy's [11] definition (one originator of GST) as viewing "the behavior of a system in terms of that of its constituent components and the interrelationships between those components [subsystems]", with the unit of analysis as the system or its subsystems. Although von Bertalanffy initially used system in the singular, he saw the systems view as the foundation of a scientific paradigm for science and humankind; following, the common reference to GST is general systems theory, with systems as a plural [18].

Understanding that systems have common features, von Bertalanffy [11] and others derived GST. Under GST, it is understood that "there are general aspects, correspondences, and isomorphisms common to 'systems'" [11] (p. 415). As GST evolved, it became more of an interdisciplinary field of study where different concepts, models, and principles were applied to systems [11], beginning the derivative to GST, systems theory. Other theoretical systems approaches beyond GST and systems theory, include "cybernetics, theory of automata, control theory, information theory, set, graph and network theory, relational mathematics, game and decision theory, computerization and simulation, and so forth" [11] (p. 416). However, for many social science disciplines, GST and systems theory have been the fields' standard. All of these theoretical systems approaches, as highlighted by von Bertalanffy [11], relate to systems problems.

Comparing different systems approaches (e.g., cybernetics, information theory), von Bertalanffy [11] concluded that systems also include interrelations within the systems. Here, GST utilizes the *system holistic principle*, borrowed from Aristotle and the Gestalt movement: the whole is greater than the sum of its parts. Thus, GST approaches systems problems within stated boundaries. Identifying these boundaries, however, becomes more challenging when dealing with social systems: "It is hard to define such a boundary to an organization" [16] (p. 397). Applying systems theory to social systems, such as organizations, can be difficult [16]. As one of its main disadvantages, when dealing with social systems, GST has become too mechanistic: "systems theory is indeed the ultimate step toward the mechanization and devaluation of man and toward technocratic society" [11] (pp. 423–424). Also, one additional concern is that social systems are composed of humans, who typically operate with an understanding of having free will [10]. Social systems, according to Kast and Rosenzweig [10], have purpose and may evolve beyond the boundaries of the systems, thus making the systems unpredictable. Some would also go as far to say that "it is futile to try to solve problems in the human sciences [human resources] with tools appropriate to the natural sciences" [12] (p. 520).

In viewing changes in a system or subsystems over time, dynamic systems theory differentiates between three system states: asymptotically stable, neutrally stable, and unstable [11]. Stability refers to how a system responds to perturbations. A system is identified as being asymptotically stable if it returns to is original state after a disturbance and unstable if it changes states [11]. It is ideal to have an asymptotically stable system when viewed by GST. When a system has been identified as unstable, the system is controlled back to its asymptotically stable state: "a system which is not asymptotically stable is made so by incorporating a controller" [11] (p. 418). Having a system that is asymptotically stable or having the ability to place controls on a system to maintain stability, adds to a system's predictability. These controls can also act as buffers to external perturbations [19], further manipulating the system, or at least a subsystem, to maintain a desired state. These controls counter, in many cases, the self-organizing processes within the system.

Systems theory has been instrumental to the social sciences and has served as a foundation for HR theory. However, systems theory has come under attack in recent years due to its inability to address complexity and non-linear systems [9,20] and its mechanistic nature when viewing human systems. To further develop the potential for expanding the use of complexity theory in HR and social science contexts, the current article focuses on describing complexity theory and its components to outline the differences between and overlaps of systems theory and complexity theory.

### *2.3. Distinguishing Boundaries of GST*

One key feature of GST is the concept of reversible and irreversible processes. For systems to be sustainable, they must have reversible processes—those that are capable of changing state and returning back to their initial state. One example of a reversible process is water and steam. Under the right conditions, water is capable of changing states to steam and is reversible in that the steam can return back to water. The problem within systems is when processes become irreversible; they tend to be unsustainable, uncontrollable, and can potentially destroy some of their own components. This follows the second law of thermodynamics as highlighted by von Bertalanffy [11] (p. 409): "The second law of thermodynamics prescribes that ordered systems in which irreversible processes take place tend toward most probable states and, hence, toward destruction of existing order and ultimate decay."

#### 2.3.1. Open versus Closed Systems

Identifying the key concepts of GST, Kast and Rosenzweig [10] highlighted that a system can be viewed as being either a closed or open system. An open system freely exchanges information, resources, and energy, whereas a closed system retains these products for its own use. Kast and Rosenzweig [10] also recognized that a system can be somewhere between open and closed as opposed to being fully open or fully closed.

A closed system is bounded. In most cases, this boundary protects the closed system, along with its systems and subsystems, from external environmental forces (e.g., airplane, automobile, and battery). An open system does not have this separation from environmental forces; it is not bounded and can be influenced from a number of forces, internal or external of the system (e.g., global warming, social movements, and terrorism).

#### 2.3.2. Complex Adaptive Systems (CAS)

Complex adaptive systems (CAS) generally refer to "open dynamical systems that are able to self-organize their structural configuration through the exchange of information, energy and other resources within their environment, are able to transform these resources in order to support action" [21] (p. Firms), and are self-organizing systems with little to no direct control over these systems from external forces. Having organic interactions within and between systems that are constantly taking place as the systems' components learn to adapt to external forces, the systems are also dynamic. CAS tend to transform to new states once the systems have learned to be adaptive to their new environment; this is termed "emergence" within the complexity literature.

A list of various definitions for CAS from the literature is provided in Table 1.

**Table 1.** Definitions of complex adaptive systems (CAS).

| Source | CAS Definitions |
| --- | --- |
| [22] (p. 732) | Responsive processes among multiple agents. A complex adaptive system cannot be created or controlled by individual actors. But the system can be influenced, nurtured, and exploited by a group of actors. |
| [23] (p. 213) | Made up of a large number of parts that interact in a nonsimple way. |
| [24] (p. 963) | A system of individual agents, who have the freedom to act in ways that are not always totally predictable and whose actions are interconnected such that one agent's actions change the context for other agents [25] (p. 2). |
| [26] (p. 279) | Composed of interacting 'agents' following rules, exchanging influence with their local and global environments and altering the very environment they are responding to by virtue of their simple actions [27] (p. 17). |
| [5] (p. 76) | Systems that exhibit the characteristics of complexity theory. |
| [28] (p. 1246) | *Self-organization* and *emergence* are central features of complex adaptive systems. |
| [29] (p. 413) | Aggregates of interacting subunits, or agents, which together produce complex and adaptive behavior patterns. |
| [30] (p. 216) | Have the capability to learn and adapt to changes in their environments. |
| [31] (p. 354) | Both emergent and intentional processes coexist and coevolve. |
| [32] (pp. 321–322) | A network of many agents acting in parallel, where control is highly dispersed, where coherent behavior in the system arises from competition and co-operation among agents themselves, where there are many levels of organization, with agents at one level serving as the building blocks for agents at a higher level, where there is constant revising and rearranging of their building blocks as they gain experience, where the implicit or explicit assumptions about the environment are constantly tested by the agents [33] (p. 7). |
| [34] (p. 691) | Heterogeneous elements that interrelate with each other and with their surroundings, and are unlimited in their capacity to adapt their behavior through experience. |
| [35] (p. 408) | Agents are connected, interdependent, and have the potential to produce non-linear (i.e., extreme) outcomes. |
| [1] (p. 334) | Complex systems—highly connected networks of semi-independent agents from which system wide patterns emerge—that can learn and adapt over time. |
| [4] (p. 1550) | A diverse alignment of connected yet independent agents that focus on systems of many interdependent components with these agents having the ability to interact, adapt, or learn by creating models to anticipate the future, in which reality can be illuminated. |
| [36] (p. 876) | Connective structures that exhibit re-entrant connections whereby energy is translated into structures that, in turn, can absorb more energy. This is aided by the absorption of information and the formation of knowledge structures that can be drawn upon in energy seeking. |
| [6] (p. 558) | Formed through the interconnection between natural systems, designed systems and social systems. |
| [37] (p. 913) | Human social systems . . . capable of independent spontaneous, self-organization. |
| [38] (p. 5) | Investigates systems that *adapt* and *evolve* while they *self-organize*. |
| [39] (p. 1290) | Cannot be reduced to the sums of their component parts because the ability to maintain the emerging properties depends more on the interdependency of the elements than on the behavior of individual components. |
| [40] (pp. 7–8) | Component parts interact with sufficient intricacy that they cannot be predicted by standard linear equations, so many variables are at work in the system that its over-all behavior can only be understood as an emergent consequence of the holistic sum of the myriad behaviors embedded within. |
| [41] (p. 443) | Embedded in the fine detail of the many entities and their interactions, not in the gross pattern of a few strong linkages [42] (p. 54). |
| [43] (p. 19) | Involve great numbers of parts undergoing a kaleidoscopic array of simultaneous interactions. |
| [44] (p. 29) | Emergent systems . . . they are shaped and developed over time through an evolutionary process. |
| [45] (p. 509) | Composed of interacting sub-units with simple individual behavioral characteristics. The interacting individuals and units combine to produce complex coordinated patterns of collective behaviors (emergence) that change and adapt. |
| [46] (p. 392) | Characterized by diversity and emergence...where the interacting agents that make up the system and the system, as a whole, is adaptive. |
| [47] (pp. 8–9) | Adaptive systems which consist of a variety of individuals with numerous relationships between each other, constantly interacting with one another, having mutual effects on one another, and thereby generating novel behavior. |
| [48] (p. 231) | A sub-set or type of system, has several properties that defy traditional science. |

**Table 1.** *Cont.*

| Source | CAS Definitions |
|---|---|
| [49] (p. 105) | Different elements are continuously interacting with each other and producing reactions that are ultimately intertwined, but in practice are often impossible to anticipate or trace afterwards. |
| [50] (p. 996) | Social systems that are diverse, non-linear, consisting of multiple interactive, interdependent, and interconnected sub-elements. They are adaptive and self-organizing, tending toward ever-greater complexity operating at the 'edge of chaos' and therefore in a constant state of innovation and dynamic equilibrium. |
| [51] (p. 363) | Agents whose interactions result in self-organization, emergence, and adaptation. |

Self-organization implies that no system constituent (or anything outside the system) has a direct or an exclusive control over its collective patterns or how these patterns change. It also means that the interactions among the system's constituents are not centrally controlled, but rather local; this localness is related to physical or cognitive dimensions. The collective, ordered patterns that emerge via self-organization in CAS are usually known as emergent properties, i.e., properties that arise or characterize a system at a certain level as the result of interactions taking place at a lower level [21] (p. Firm).

Different characteristics that make up CAS from the literature are provided in Table 2.

**Table 2.** Characteristics of complex adaptive systems (CAS).

| Source | Complex Adaptive System Characteristics | Description |
|---|---|---|
| [22] (pp. 733–735) | Fitness Landscape | The surroundings in which living beings exist and behave . . . . changes continuously . . . determines the effectiveness of the behavior of the acting agents. |
| | Adaptive Capability | Emergent properties . . . characterized by a specific configuration of activities . . . to meet external demands. |
| | Integration | Involves cultural consensus and clarity, in the form of *collectively* shared rituals and jargons. |
| | Differentiation | Involves subcultures and islands of clarity, in the form of *different* rituals and jargons. |
| | Fragmentation | Involves jargons and rituals loaded with *ambiguity*, in the form of irony, paradoxes, or contradictions. |
| [23] (p. 216) | Modularity | The extent to which an activity system is decomposable into separate identity-retaining subsystems of activities. |
| | Concentration | The extent to which an activity system exhibits certain central activities that are interdependent with many peripheral activities. |
| | Openness | The extent to which a focal activity system exhibits coevolutionary interdependencies between its own activities and those of external organizations. |
| [26] (pp. 281–282) | Schemas-Diversity | Created by actors in an interactive relationship and provide a framework enabling agents to anticipate the results of their actions. |
| | Interaction-Interdependence | Heterogeneous agents which inter-relate with each other and with their surroundings and are unlimited in their capabilities to adapt their behavior based on their experience. |
| [5] (pp. 76–77) | Inter-relationships | Individual components affect each other and influence actions. A system is complex if it consists of many varied interrelated parts. |
| | Adaptability | Open systems affect, and are affected by, external environmental systems. Open systems must be capable of reacting to changes in external environmental systems. |
| | Self-Organization | Systems tend toward order or self-organization. Individuals act in similar ways in proximity to and in concert with each other. |
| | Emergence | The whole is greater than the sum of the parts. |
| | Feedback | Information is circulated, modified, and returned. |
| | Non-linearity | Small changes in the initial conditions or external environment can have large and unpredictable consequences in the outcomes of the system. |
| [29] (pp. 413–418) | Strange Attractors | Collections of actors with simple individual behavioral characteristics combine to produce complicated coordinated patterns of group behaviors that change and adapt to environmental circumstances. |
| | Agent Cooperation | The structuring of connections between collections of agents and how they interact to produce attractor patterns. |
| | Strategic Leadership | Influence the context and structure of agent activity. |

**Table 2.** *Cont.*

| Source | Complex Adaptive System Characteristics | Description |
|---|---|---|
| | Dissipative Structures | Systems that respond to increasingly complex environments by importing greater resources from outside and exchanging more resources within their boundaries to achieve greater degrees of fitness. |
| | Conveying History | Systems exhibit non-linear relationships among variables, including time, and the future behavior of these systems depends on their initial starting points and subsequent histories. |
| [31] (p. 356) | Adaptive Tension (region of complexity) | Emerges from external constraints and corresponds to the energy differential between the system and its environment. Between the 'edge of order' and the 'edge of chaos'. |
| | Enabling Leadership | Design systems in which distributed intelligence can easily emerge. |
| | Adaptive Advantage | Increase agents' connectivity and receptivity inside an organization in order to enhance cooperation and learning. |
| | Requisite Variety (boundary spanning) | Interacting with actors external to one's network brings diversity and novelty into the system, allowing it to create new knowledge. |
| [4] (p. 1555) | Diversity | Diversity and individuality of components. |
| | Interactions | Localized interactions among those components. |
| | Autonomous | An autonomous process that uses the outcomes of those interactions to select a subset of those components for replication or enhancement. |
| [6] (pp. 564–565); [37] (pp. 913–915) | Continuous Varying Interactions (CVI) | Local and remote, non-linear interactions, positive and negative feedbacks, large number of elements, continuous interaction, connected open systems, rich interactions, and relationships coevolve. |
| | Patterns Development (PD) | Patterns emerge, stable and far-from-equilibrium, origins of patterns, and patterns (stabilizing, de-stabilizing, or both). |
| | People Factors (PF) | Whole system ignorance, histories, and space possibilities. |
| | Self-Organization (SO) | Creation of environments to develop their own plans and future. |
| [38] (p. 5) | Non-linearity | Small changes in the input or the initial state can lead to order of magnitude differences in the output or the final state. |
| | Emergence | Order emerges from complex interactions. |
| | Irreversibility | Change is path dependent. |
| | Non-predictability | Unpredictability of system outcomes. |
| [39] (p. 1290) | Landscape | Shaping the cluster in which individual organizations adapt. |
| | Positive Feedback Loops | Amplify and reinforce the small actions of actors. |
| | Boundary Constraints | Dampen or limit the self-organizing processes. |
| | Novel outcomes | Unpredictable and only known in retrospect. |
| [43] (pp. 25–26) | Parallelism | Permits the system to use individual rules as building blocks, activating sets of rules to describe and act upon the changing situations. |
| | Competition | Allows the system to marshal its rules as the situation demands, providing flexibility and transfer of experience. |
| | Recombination | Generating plausible new rules from parts of tested rules. |
| [44] (pp. 29–30) | Framing | Describes whether a system is perceived as being *simple*, *complicated*, or *complex*. |
| | Structure | The physical or conceptual nature of the system . . . . embodies the following structure: a large number of elements, interaction between the elements, interactions are rich, interactions are non-linear, interactions have a short range, interactions have loops, the system is open, disequilibrium rules the system, the system has a history, each element is ignorant of the behavior of the system as a whole. |
| [45] (p. 505) | Non-linearity | No Description |
| | Unpredictability | No Description |
| | Sensitivity to Changes in Initial Conditions | No Description |
| | Adapting to Environment | No Description |
| | Oscillating Between Stability and Instability | No Description |
| | Emergence | No Description |

**Table 2.** *Cont.*

| Source | Complex Adaptive System Characteristics | Description |
| --- | --- | --- |
| [46] (pp. 392–394) | Complexity Dynamics | The emergent processes through which CAS form and operate. Key processes include self-organization, emergence, and bonding. |
| | Enabling Conditions | The necessary conditions under which complex behavior will occur. Enabling conditions include the presence of dynamic interaction, interdependence between agents, heterogeneity in the system, and tension. |
| [47] (p. 9) | Connectivity and Interdependence | Responsible for a variety of feedback mechanisms, which occur within an organization. |
| | Feedback | Positive feedback moves the system away from its equilibrium and is a driver for change and instability. Negative feedback tries to bring the system back. |
| | Far-From-Equilibrium | At the edge of chaos where the system experiences spontaneous self-organization and emergent order. |
| | Emergence | New order and space-of-new-possibilities. |
| [48] (p. 231) | Path Dependent | Sensitive to initial conditions. |
| | Non-Linearity | React disproportionately to environmental perturbations . . . . The ‘butterfly effect’. |
| | Emergence | Each organization’s internal dynamics affect its ability to change in a manner that might be quite different from other organizations. |
| | Adaptive | Have equal capacity to adapt and evolve . . . . self-organization. |
| [49] (pp. 105–110) | Connectivity | The linkages that a system has with its neighboring systems. |
| | Co-Evolution | The tendency of several systems, or several sub-systems within one main system, to move together towards new forms of existence or new states of development. |
| | Reinforcing Cycles | Amplifying loops between systems or units (positive and negative feedback). |
| | Non-Linearity and Sensitivity to Initial Conditions | Refers to the outcomes of CAS, which differ from the outcomes of simple systems. |
| | Self-Organization | Pattern and regularity emerge spontaneously in a system. |
| [52] (pp. 12–17) | Non-linearity | A complex system contains many constituents interacting non-linearly. |
| | Open System | A complex system is an open system in which the boundaries permit interaction with the environment. |
| | Feedback Loops | A complex system contains feedback loops that can be amplifying (positive feedback) and balancing (negative feedback). |
| | Scalable | A complex system possesses a structure spanning several scales (fractural structures) that are self-similar. |
| | Emergence | No Description |
| | Natural Behavior Elements | No Description |
| | Exchange Energy | No Description |
| | Share Information | No Description |
| | Align Choices for Interaction | No Description |
| | Coevolve Together | A complex system is capable of co-evolution with emergent behavior. |

Given the various representations for the characteristics that make up CAS (see Table 2), CAS display at least the following characteristics: path dependence, non-linearity, emergence, and adaptiveness [48]. Figure 1 identifies the basic tenets for most CAS. Being sensitive to small changes is elemental to CAS’ path-dependent characteristic. Path-dependent systems are “sensitive to their initial conditions, so that the same force might affect seemingly similar organizations [systems] differently based on their histories” [48] (p. 231). If small changes in a system can lead to big effects and, within the same system, big changes can also have minimal effects, then these effects can be difficult to predict [37]. This inability to predict future states of a system is indicative of a non-linear system. In addition to the aforementioned information, as in Section 2.4, emergence, according to Lindberg and Schneider [48], refers to a system’s interactions that lead to a change that could result in an organization being different from other organizations. This emergence also makes CAS irreducible; due to its emergent properties, higher-order states cannot be reduced to their original lower-level states. Thus, a phase transition typically occurs, changing the initial lower-level states. Having the ability to be adaptive, operating between chaos and order, is one of the unique characteristics of CAS. By operating between chaos and order, CAS avoid the status quo while at the same time avoiding complete chaos. This balance is self-organizing and allows CAS to learn and evolve into new emergent states.

COMPLEX ADAPTIVE SYSTEMS (CAS)

- Path Dependent
- Systems have a History
- Non-Linearity
- Emergence
- Irreducible
- Adaptive
- Operates between Order and Chaos
- Self-Organizing

**Figure 1.** Tenets of complex adaptive system (CAS).

### *2.4. Complexity Theory*

Interactions drive a system toward new emerging states as it coevolves within its environment [53]. Complexity theory, synonymous with complexity science in the literature, is best described in the following quote:

> Complexity science targets a sub-set of all systems; a sub-set which is abundant and is the basis of all novelty; a sub-set which is evidenced in biology, chemistry, physics, social, technical and economic domains; a sub-set which coevolves with its environment; a sub-set from which structure emerges. That is, self-organization occurs through the dynamics, interactions and feedbacks of heterogeneous components . . . . This sub-set of all systems is known as complex systems. [53] (p. 12)

Having the potential of being able to provide insight into organizational change dynamics, which have been insufficiently modeled in the social sciences [32], complexity theory is more frequently found in the literature today and is showing new promise for disciplines studying complex systems. Table 3 highlights some of these areas.

**Table 3.** Complexity theory applications.

| Source | Context |
|---|---|
| [32,47,50] | Change in organizations |
| [1] | Colleges and universities |
| [31] | Communities of practice |
| [54] | Complexity in practice |
| [6] | Ecosystem–grass management |
| [4,28] | Emergency responders and trauma centers |
| [24,35] | Entrepreneurship, corporate entrepreneurship |
| [7,55] | Evaluation practice |
| [39] | Industry clusters in China |
| [5] | Information technology industry |
| [46] | Mentoring relationships |
| [56] | Multi-business organizations |
| [26,34] | Organizational learning |
| [23] | Organizational strategic renewal |
| [22,29] | Organizations |
| [57] | Policy implementation |
| [5] | Project management |
| [51] | Public management |
| [2,32,54,58] | Strategic management and development |
| [30,41,59] | Supply chain management and disk management |

The following propositions relate to complexity theory: "Simple systems give rise to complex behavior. Complex systems give rise to simple behavior. And most importantly, the laws of complexity hold universally, caring not at all for the details of a system's constituent atoms" [60] (p. 304). Complexity theory differs in how it perceives the principle of system holism. Rather than viewing the whole as the sum of its parts, complexity theory asserts the following: "The whole is different from the sum of its parts and their interactions" [61] (p. 77). Through emergence, the whole cannot be reduced to the original parts, the whole is considered a new entity or unit. The whole is "qualitatively different from their parts . . . . They cannot be meaningfully compared–they are different!" [61] (p. System holism).

Table 4 provides a list of definitions and descriptions found in the literature relating to complexity theory/science.

**Table 4.** Descriptions of complexity theory.

| Source | Complexity, Complexity Science/Theory Descriptions |
|---|---|
| [24] (p. 963) | A study of order-breaking and order-creating processes. |
| [24] (p. 964) | A study of changing patterns of order, self-organization, or constrained diversity. |
| [26] (p. 279) | Sets out to devise mechanisms to create and maintain complexity, and to produce tools for its description and analysis. |
| [5] (p. 76) | Provides an opportunity to re-examine reductionist and mechanistic thinking thereby providing a more holistic view. |
| [28] (p. 1246) | Complex systems made up of interdependent agents that interact, learn from each other, and adapt their behaviors accordingly. |
| [30] (p. 216) | A system made up of a large number of parts that interact in a nonsimple way. |
| [62] (p. 546) | Describes the evolutionary phases of a system's structure and function. |
| [31] (p. 355) | Studies the behavior of complexity interacting, interdependent, and adaptive agents under internal and external pressures. |
| [31] (p. 356) | Provides an integrative and dynamic framework to understand the interaction patterns in networks of interdependent agents who interact and are bound by their common needs or objectives. |
| [32] (p. 320) | Provides insight into those dynamic processes of change in organizations. |
| [58] (p. 968) | Small changes in the interaction pattern of a large number of rule-abiding agents can have big effects. |
| [57] (p. 430) | Sensitivity to initial conditions, negative and positive feedback processes, disequilibrium, and emergent order. |
| [54] (pp. 796–797) | Made up of a very large number of autonomous elements . . . . dynamic, interactive, governed by micro-rules, exhibit 'butterfly effects', non-linear, and exhibit replicated patterns. |
| [34] (p. 688) | Made up of heterogeneous elements that interrelate with one another and with their surroundings. |
| [35] (p. 404) | Focuses on the underlying dynamics that give rise to a broad range of outcomes in all social systems . . . . to understand emergence in its most fundamental form. |
| [4] (p. 1555) | A form for investigating the properties and behavior of the dynamics of non-linear systems. |
| [36] (p. 875) | A body of theory about connections. |
| [37] (p. 911) | A perturbation, or disturbance, to a system. |
| [63] (p. Complexity theory) | A field of research that explores how independent agents interact with each other in a variety of ways. |
| [38] (p. 1) | The dramatic increase in the number and heterogeneity of included components, relations, and their dynamic and unexpected interactions. |
| [39] (p. 1282) | Highlights spatial self-organization, non-linearities, plurality of equilibria, and the importance of coevolutionary relationships. |
| [44] (p. 29) | Describes non-linear systems that are mechanistic, unpredictable, and without memory. |
| [45] (p. 504) | Suggests this level (those operating between top management team and middle management) is the collection of people in the best position to provide the impetus for organizational adaptation. |

**Table 4.** *Cont.*

| Source | Complexity, Complexity Science/Theory Descriptions |
|---|---|
| [46] (p. 392) | Looks at how 'order, structure, pattern, and novelty arise from extremely complicated, apparently chaotic, systems and conversely, how complex behavior and structure emerges from simple underlying rules' (Cooke-Davies et al., 2007, p. 52). |
| [17] (p. 30) | The irreducibility of the behavior of systems to the behavior of the constituent components . . . . It calls for the investigation of the interaction between systemic components at different levels of description. |
| [21] (p. 161) | Aims to better understand and predict behavior of natural systems. |
| [47] (p. 8) | Moves away from linear cause-and-effect mechanistic view . . . towards a more organic world view characterized by non-linear behavior, uncertainty, and unpredictability. |
| [49] (p. 105) | A rich set of concepts derived from the advancements of natural sciences. |
| [64] (p. 519) | Comprised of numerous interacting agents, each of which acts on the basis of local knowledge rules. |

Complexity science has developed three schools of thought: reductionistic complexity science, complexity thinking, and soft complexity science, also known as the metaphorical school [65,66]. The reductionistic school reduces elements into lower-level components and develops rules of interaction between the lower-level elements and the higher-level elements [65] as a means of explaining new emergent properties; here is where physics addresses the theory of everything. Complexity thinking focuses on what cannot be explained [65]. The epistemology is that knowledge concerning our environment is always incomplete; complexity thinking focuses on our limits of this incomplete knowledge [65]. The last school, the metaphorical school, believes that the "social world is intrinsically different from the natural world" [66] (p. 20) and challenges the Newtonian worldview [65] by viewing complexity through a connectionist perspective where causal connections cannot be identified, hence, are too simplistic compared to the whole system when analyzed. Rather than viewing the world as a mechanistic entity, the metaphorical school views the world as an *organic entity* [65]. In the current article, the authors take the perspective provided by the metaphorical school in which concepts such as "*connectivity*, *edge-of-chaos*, *far-from-equilibrium*, *dissipative structures*, *emergence*, *epi-static coupling*, *coevolving landscapes*, etc.," [66] (p. 20) have been identified in explaining metaphorically, complex systems.

The basic tenets of complexity theory are non-linear dynamics, chaos theory, and adaptation/evolution [15]; others include emergence, self-organization, feedback, and chaos [21]. Complexity theory views systems as being non-linear, thus future states are unpredictable. As a system transitions from simple to complex, the predictive mechanisms become less reliable. Chaos is deterministic and linear, with mathematical meaning [63], and has sensitivity to its initial conditions [67]. Complexity theory applies mathematical modeling of linear and predictable states when viewing chaos, whereas it employs CAS to view unpredictable, non-linear systems. Using mathematical modeling, chaos identifies the global patterns from the components' interactions in self-organizing systems [21], while CAS identify the interactions from these components. A key element of CAS involves emergence. Emergence occurs when the interactions from the system components tend to lead to new states, contributing to the system's unpredictability. The conditions of feedback, evolution, and adaptation all refer to a system's ability to learn and can be found in both chaos and CAS.

Complexity theory addresses open systems compared to closed systems. This is a major distinction of complexity theory compared to other theoretical systems approaches. This distinction goes against the second law of thermodynamics and is where complexity theory operates. Nearly all of the systems of interest in complexity theory are open systems [61] that include the components of self-organization and emergence. Related to the second law of thermodynamics, rather than irreversible processes causing the system to become self-destructive [11], the processes, self-organization and emergence, evolve new system states that are sustainable.

In its most basic form, complexity theory involves the primary concepts of chaos and CAS, along with the tenets of path dependence, system history, non-linearity, emergence, irreducibility, adaptiveness, operating between order and chaos, and self-organization, as portrayed in Figure 2. Chaos is supported by self-organization, adaptation/evolution, feedback, and deterministic systems, and CAS are supported through self-organization, emergence, adaptation/evolution, feedback/history, and nondeterministic systems. For the current article, the authors identify emergence to be primarily associated with CAS and identify complexity theory as being composed of two concepts, chaos and CAS. The authors realize, and represent (see Figure 2), that there is some overlap between the two systems and that emergence could be included in some chaotic states.

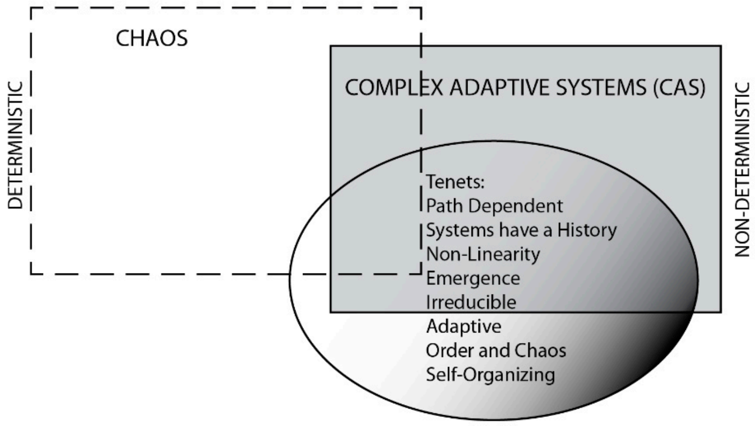


**Figure 2.** Complexity theory.

In relation to the purpose of the current research project, CAS are the model that is recommended for addressing today's complexity in the social sciences. By implementing CAS, complexity theory could operate in parallel with systems theory. While GST can operate under the principle of system holism from a reductionistic perspective, complexity theory could expand the social sciences by providing a perspective counter to the principle of system holism that incorporates a connectionist approach rather than reductionism. The following section discusses further the differences between GST and complexity theory, including CAS.

## *2.5. Differentiating GST from Complexity Theory*

There are multiple differences between GST and complexity theory. Presented in the following section are further distinctions between the two, including the following: the principle of system holism, open and closed systems, linear and non-linear systems, and the application of the concept of irreducibility.

### 2.5.1. The Principle of System Holism

Complexity relates to the emerging whole, which differentiates complexity theory from GST. As GST follows the principle of system holism—that the whole is greater than the sum of its parts—complexity theory operates on the principle that "the whole is different from the sum of its parts and their interactions" [61] (p. System holism).

### 2.5.2. Open and Closed Systems

Theoretical systems approaches identify mostly with closed systems, but not always. There are a number of GST approaches that look at open systems, especially those that look at social systems. However, complexity theory and CAS are predominantly associated with open systems. The literature portrays CAS as unordered, chaotic, and complex in which patterns can emerge (open system). In contrast, GST is related to order, with structured patterns both simple, and complicated (closed system) [37]. The primary distinction between open and closed systems relates to the second law of thermodynamics, which applies primarily to closed systems and not to open systems. As stated previously, the second law of thermodynamics is associated with theoretical systems approaches, whereas complexity theory goes against the second law of thermodynamics due to the tenets of self-organization and emergence.

### 2.5.3. Linear and Non-Linear Systems

Theoretical systems approaches view systems structurally, where "individuals and subsystems cannot be isolated from the larger systems" [17] (p. 20) and view the system state (its current state) as an approximate future state [67]. The non-isolation of individuals and the norm of subsystems to causality and linearity, which relate to rules-based systems and to systems theory: "Systems theory recognizes the existence of multiple forms of causality: linear, linear chains, multiple simultaneous causes, and mutual causation" [67] (p. 24). In contrast, complexity theory views systems as a process [17] that is self-organizing. Systems are non-linear and unpredictable and therefore cannot be analyzed or managed using traditional techniques, defying prediction and linear causal laws [37]. Complexity and CAS move away from reductionist thinking (analyzing individual elements) to a connectionist perspective in which the interactions among and between elements are viewed along with the system's adaptability to change to environmental forces [68].

**Rules-Based Approach.** Rules play an essential role in the emergence of mechanistic systems that are not typically self-organizing but result from random mutations [26]. The prediction of these rules-based systems come from the form of the rules or schemas [26]. Rule-based behaviors are an aggregate of the system's interactions and are linear or predictable [58]. Small changes in interactions in rule-based systems can result in large effects [58].

**Connectionist Approach.** This perspective views systems as being self-organizing and participatory with respect to all agents, where the connections and interactions among the individual agents result in emergence [26], making prediction less likely. Emergence occurs from non-linearity and can be viewed as being multiplicative [58] or exponential and cannot be predicted based on traditional correlation and cause-and-effect statements [26] or from predefined rules. Agents refer to entities within systems such as individuals, teams, functions, departments, and organizations [49].

Adopting a connectionist approach, we understand that the system's outcomes cannot be predicted due to the fact that too many actors are in play and due to the complexity of the system: "As the number of units—and relationships—grow, we cannot master the increased complexity" [49] (pp. 105–106). The authors do, however, believe that the processes can be understood and managed through the interactions that take place among the agents involved [69].

This position is similar to Uhl-Bien and Marion's [70] (p. 637) mechanism-based theorizing in their presentation of complexity leadership theory: "With mechanisms, we look for patterns of interaction that are recognizable across situations to identify an intelligible answer to the question of why something happened in situations where specific causes and effects are not identifiable".

### 2.5.4. Irreducibility

A final distinction between GST and complexity theory is irreducibility. Irreducibility indicates that the "higher-level entity is not merely aggregated, it is *holistic* (i.e., possessing limited direct relationship to its constituent parts)" [70] (p. 637). This is similar to the concepts of reversible and irreversible processes. The former, reversibility, is a process in which the lower-level states (the parts) aggregate into a higher-level state (sum of the parts) then back again to the same constituent parts, and reversibility is synonymous with systems theory. Alternatively, irreversible processes, sometimes referred to as *non-decomposable elements* [71], have the same ability to convert lower-level states (the parts) into higher-level states. However, this higher-level state is different than the sum of the parts, partially due to emergence and self-organization. This irreversible process cannot be reduced back to its original components and is synonymous with complexity theory.

### 2.6. Complexity Theory for the Social Sciences

Complexity theory has been described as a new science in which "nobody knows quite how to define it, or even where its boundaries lie" [72] (p. 9). Complexity theory has also been portrayed as a "paradigm shift from previous science" and as a "new paradigm" [15] (p. 353).

Complexity theory has been portrayed in two ways. The first places GST as the overarching theory for complexity theory and CAS. For example, Yawson [9] presented complexity theory as a subset of systems theory, positioning GST as the grand theory and complexity theory, CAS, and systems theory within its umbrella. However, later in the same research study, Yawson [9] identified three interrelating elements to complexity theory that could not be accounted for by GST: non-linear dynamics, chaos theory, and adaptation, providing some separation between GST and complexity theory. Other literature has described complexity theory as a new science, indicating that complexity theory was separate from other theories. This second portrayal identified GST and complexity theory as two separate theories, with systems theory under GST and CAS residing under complexity theory. Developed from scientific and mathematical fields, complexity science was influenced by the "original systems sciences of cybernetics, information theory, and General Systems Theory" [73] (p. 7), while remaining a new science, separate from GST. For the current article, the authors adopted Goldstein et al.'s [73] position that complexity theory is separate from GST with CAS and chaos theory residing underneath complexity theory. The authors recognize that there is some overlap between GST and CAS, as shown in Figure 3, however, still contend that complexity theory is separate from GST and other theoretical system approaches (e.g., systems theory, cybernetics, and theory of automata). For the social sciences, it is argued that future research should include examinations of the CAS tenets (path dependency, history, non-linearity, emergence, irreducibility, adaptability, balance between order and chaos, and self-organizing). The interactions within organizations are complex and can be explained better through the lens of complexity theory and CAS than by the other theoretical system approaches.

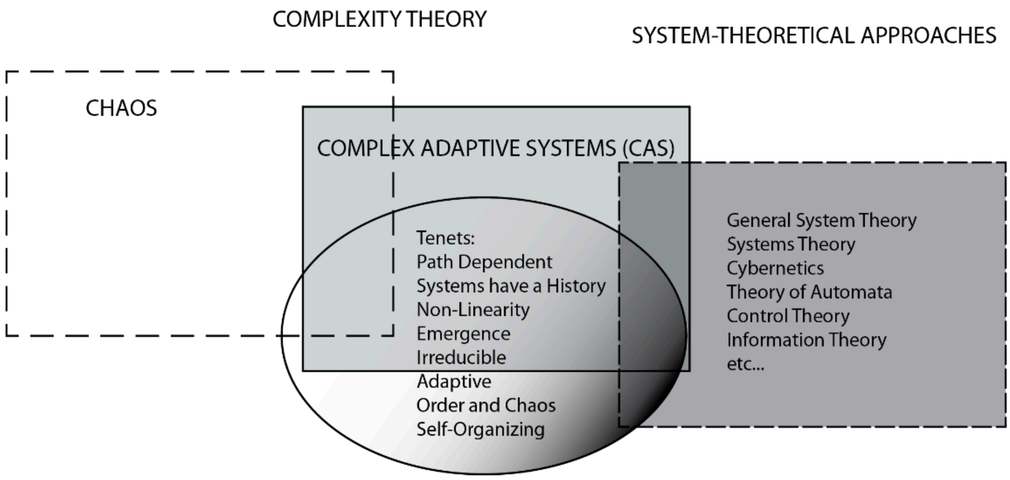


**Figure 3.** Complexity theory and theoretical system approaches.

## 3. Addressing Complex Issues and Wicked Problems

In Figure 3, we demonstrate that the coverage of complexity theory involves chaos and CAS, along with complexity theory tenets, some of which are shared with GST and systems theory. In the following sections, we identify three future areas of study that are critical for the practice of social science and the examination of social systems in which complexity theory and complexity thinking, and not systems theory, will be required for scholars and scholar-practitioners as they navigate through tomorrow's complexity.

### 3.1. Wicked Problems

Problems are typically categorized as being simple, complex, or wicked [74]. Simple problems have an identifiable problem and solution, whereas complex problems typically have an agreed upon problem but differing potential solutions. For the third type of problem, wicked problems, there is no agreed upon problem or solution. Churchman defined wicked problems as "that class of problems which are ill-formulated, where the information is confusing, where there are many decision makers and clients with conflicting values, and where the ramifications in the whole system are confusing" (as cited in [75] (p. 200)).

Wicked problems are made up of the following properties: indeterminacy in problem formulation, non-definitiveness in problem solution, non-solubility, irreversible consequentiality, and individual uniqueness [76]. Wicked problems have no definitive problem statement and hence have no definitive solution, most often having no solution at all; wicked problems consist of irreversible characteristics due to complexity, which adds to the complications caused by constantly changing variables, and each wicked problem is each unique in its own context and structure.

Wickedness has been accepted in most disciplines today in such a manner that it has largely become the norm, relating to human issues such as "global climate change, sustainability, stem cell research and usage, resource management, terrorism, and urbanization" [76] (p. 2). Attempting to address wicked problems using traditional linear methods leads to *partial analysis*, at best, and deception that the problem has been solved [76]. These linear approaches have generated dissatisfaction with decision making, planning, and implementation [77]. Such attempts have also been described as trying to tame the untamable, in which the "inadequacy lies in the intellectual roots of these traditional approaches and skill sets" [76] (p. 1). The problem with trying to address wicked problems using the traditional linear methods that are applicable when using systems theory is that these particular problems are resistant to linear protocols [76]. Instead, researchers have called for awareness, acceptance, and new innovative strategies for addressing wicked problems [76]. One such method, in opposition to the linear systems approach, is the adaptive, participatory, and transdisciplinary method [76]. Other methods incorporate collaborative strategies that involve social learning to address wicked problems. However, these collaborative strategies or interventions must be structured using a complexity framework as opposed to a systems framework: "Social learning is more likely to be successful if it remains a self-organizing, complex adaptive systems that coevolves as stakeholders meet, interact, and inform one another's actions" [78] (p. 16).

As a discipline, the social sciences would be better poised to address wicked problems using complexity theory and complexity thinking methodologies in lieu of systems theory or systems thinking. Systems theory has been identified as being incapable of addressing wicked problems: " . . . addressing wicked problems calls . . . to forge new ways of thinking, leading, managing, and organizing that recognize the complexity of the issues and processes" [77] (p. 722). The importance of complexity theory to scholars and scholar-practitioners will increase as wicked problems become more prevalent in their fields. This point is best illustrated by Roberts [78] (p. 16) when she stated the following: "Wicked problems will be with us for some time."

### 3.2. Decision Making and the Cynefin Framework

To better make sense of complexity in organizations, Kurtz and Snowden [79] developed what they called the Cynefin framework. This framework originated in the knowledge management discipline but later expanded into multiple fields (e.g., training, culture change, and leadership) and has been used for multiple purposes (e.g., decisions, perspectives, and conflict) [79]. The original framework was presented in a two-by-two matrix involving chaos, complex, knowable, and known categories for each matrix (clockwise from the bottom left). In the middle of all four categories, Kurtz and Snowden [79] identified the state of disorder that could be occupied by any of the four states as they interact or transition between states [37]. Other representative models present the four categories as being chaotic, complex, complicated, and simple (clockwise from the bottom left). This representation is shown in Figure 4. Here, chaotic is best represented by unknowables, complex with unknown unknowns, complicated with known unknowns, and simple with known knowns. This construct of known represents things that are known to the collective, the entity of interest [79].

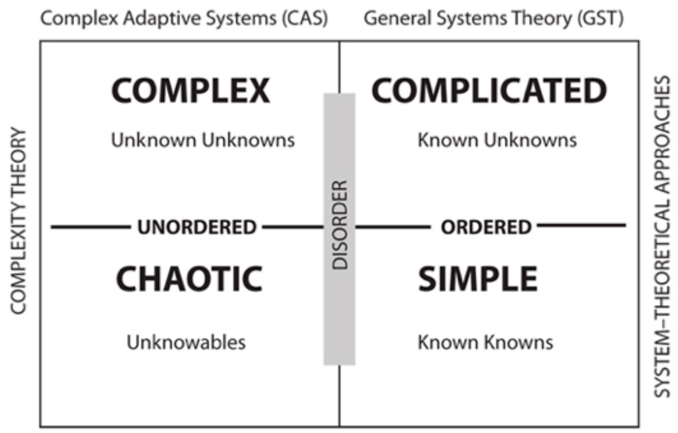


**Figure 4.** Complexity theory and sensemaking.

Chaotic states have been associated with having no cause and effect relationships, while complex states were identified with CAS in which cause and effect relationships "are only coherent in retrospect and do not repeat" [79] (p. 468). The left half of this framework is best associated with CAS (see Figure 4). The state of complicated has been associated with having cause and effect relationships and with systems thinking, while the simple state has been related to predictable cause and effect relationships and best practices [79]. The right half of this framework is best associated with systems theory. As shown in Figure 4, the overarching theory is complexity theory with CAS associated with complex and chaotic states and systems theory associated with complicated and simple states. The disorder represents the fuzzy border between the states, meaning that some complicated states could have a touch of complexity up to a point. Beyond that point, the state experiences a phase transition. This point in which a phase transition occurs differs with each system dependent upon the initial laws of complexity and unique composition. Once a state experiences a phase transition, the new state is irreducible and cannot be reduced to its initial composition.

Potential uses for this sensemaking framework (Cynefin framework) include *contextualization* and *alternative history* exercises (see [79] for additional examples). Contextualization is a brainstorming exercise in which the framework is used to draw multiple perspectives around a specific issue or event [79]. This exercise offers different solutions to specific issues by discussing how solutions would be portrayed in each of the four states (i.e., chaotic, complex, complicated, and simple). A second example includes an alternative history exercise, which involves discussing the history of a specific entity or event, identifying when and why within the framework critical turning points occurred [79].

This sensemaking framework provides a visual representation of how different states can occupy independent and interdependent states, depending on the context. In applying this sensemaking framework to contextualize problems of social systems, a shift from its current state within the complicated domain (systems theory) to the complex domain (complexity theory and CAS) to better prepare scholars and scholar-practitioners to address complexity and wicked problems will be necessary.

## 4. New Directions for Social Systems Research

The following section outlines a few areas in which the social sciences could begin to include more complexity theory research. The following sections include a discussion on expanding more non-reductionistic methods and theories for social systems. Also, on the methods side, implementing more research utilizing social network analysis along with some brief examples is discussed. Last is a call for scholars and scholar-practitioners to begin developing more complexity-related theories. These three recommended areas are presented only as a beginning, to start the process of moving the social sciences into the field of complexity, providing scholars and scholar-practitioners with the tools and new theories to operate in the current environment, which includes globalization, sustainability, and wicked problems.

### 4.1. Incorporating More Non-Reductionistic Methods

Reductionistic methods have been identified as methods of reducing "complex phenomena into elementary parts and processes" [11] (p. 409). Reductionistic methods work well as long as the observed agents can be isolated to causality, identifying the relationship between a few variables at one point in time) [11]. Reductionistic methods involve linear models that come with specific assumptions as identified by Jayanti:

> Such assumptions include the premise that closed models are adequate for modeling processes occurring in open systems, that models can be universally applied and do not need to specify where and when they should be used, that a system is equal to the sum of its parts, that time is reversible, that causality is linear, that future outcomes–like the future itself–can be predicted, and that environments are relatively static and tend toward equilibrium. [80] (p. 103)

However, even with the successes that have been achieved in the fields of physics and biology by using reductionistic methods, questions still remain [11]. Scientists have begun to understand that the interactions within and among systems must also be observed and understood, resulting in too many associations to be studied using simple causality methods. This problem was identified by von Bertalanffy [11] (p. 411) as the problem of organized complexity: "There loomed the problem of 'organized complexity,' that is, of interrelations between many but not infinitely many components".

Given today's complexity, globalization, and interconnectedness, von Bertalanffy [11] highlighted that reduction to simple particles using laws of physics is not practical. Rather, von Bertalanffy [11] (p. 423) supplanted reductionism with "new categories of interaction, transaction, organization, teleology, and so forth", which also included developing newer techniques.

### 4.2. Network Analysis to Look for Relevant Nodes in a Network

Network analysis has grown in recent years due to advances in technology and new methods of analysis. More specifically, social network analyses identify the "contacts, ties, and connections, the group attachments and meetings, which relate one agent to another and so cannot be reduced to the properties of the individual agents themselves" [81] (p. 3). In this description by Scott [81], social network analysis can be used as a method to address complexity using connectionist methods as opposed to traditional correlational techniques. Social network analysis is capable of identifying patterns, clusters, and strong ties (interactions) from large sets of data linked to human behavior. When viewing social activity through the lens of complexity theory, it is the patterns, clusters, and interactions that we wish to examine further once they have been identified. Equated by some to relational sociology, social network analysis encompasses a theory of the social world [81].

To examine the random nature of networks, Richardson [61] constructed an experiment that simulated 100,000 networks each with 10 nodes, two inputs, and the same random rules of association. In viewing these networks all irrelevant nodes (frozen or leaf nodes) were removed from each network. This resulted in each network having roughly 60% of their nodes being relevant or connected nodes [61]. Although this 60% estimate is not universal, it does, however, make the point that relevant nodes within a network can be scrutinized for further analysis. Identifying relevant nodes, patterns, or clusters begins the process of new discovery in social systems that were not possible previously.

When attempting to optimize a system the rules of optimization need to be acknowledged. One of these rules states the following: "Optimization of a system's parts does not (necessarily) lead to an optimal system, and vice versa" [82] (p. This short analysis). Given this rule, it would be essential to identify which set of relevant nodes could be optimized in order to better optimize the whole system. This supports the *redundancy of potential command principle*: "To control a complex system we must first have a sufficiently good representation of it" [82] (p. Redundancy). Although the prediction of a complex and open system is not entirely possible, in part, due to unknown conditions (e.g., environment, emergent properties), near prediction is dependent upon extracting meaningful relationships [82]. Utilizing social network analysis provides scholars and scholar-practitioners with the tools to not only analyze social systems, but also to optimize these systems.

### *4.3. New Complexity-Related Theories*

With an "apparent shift toward complexity-based inquiry in sustainability research" [83] (p. Abstract), newer methods are being called to support this complexity-based inquiry. Porter and Reischer [83] highlighted that, in the context of sustainability, reductionistic methodologies were least effective. They called for researchers to move beyond the "standard boxes-and-arrows thinking" [83] (p. Conceptual framework) when addressing complexity and wicked problems. In this context, complex problems cannot be answered using simple linear epistemology [80].

In response to their own call, Porter and Reischer [83] situated sustainability as a CAS, defined as being multilevel and ever-evolving. Much in the same manner as Porter and Reischer, [83] identified sustainability as being a CAS, so too can many constructs currently being researched in the social sciences (e.g., leadership, diversity, teams, workplace engagement) be categorized. Also, new multilevel, networked, and complexity-situated theories need to be developed within the literature in an effort to expand the theory and knowledge base of the social sciences, as well as to increase the fields' utility. Aside from this conceptualization, complexity-related theories need to be operationalized prior to being tested [8,12], providing further support for a theory's utility to the field.

Additional calls have been found in the literature. For example, Yawson [9] highlighted the need to re-conceptualize complexity theory for one's discipline and noted that a conversation needs to occur within each discipline (see also [84]). Theorizing within the social sciences to examine social systems' need to branch out to complexity thinking as a way of incorporating different epistemologies or *thought-universes*, Jayanti [80] (p. 110) stated the following: "it may be necessary to create entirely new models to more fully over-come the limits of Newtonian assumptions." Similar calls identified chaos and complexity theory as providing a means of developing new perspectives for the social sciences to examine social systems, resulting in a better understanding of today's complex issues [8].

## 5. Conclusions

Systems theory has been identified as a foundational theory for some disciplines, providing a uniform language for those disciplines [67]. However, this perspective has been challenged, and some research has identified systems theory as being disconnected from research and practice: "Its relevance and use in the practice ... remains a myth" [9] (p. 70). These disciplines cannot remain isolated in systems theory or systems thinking when much of the scientific community has already begun transitioning to complexity theory. For example, Chandler, Rycroft-Malone, Hawkes, and Noyes [85] (p. 462) highlighted complexity theory's prevalence in the healthcare industry: "Complexity theory has progressively entered the lexicon of healthcare sciences." Foster [36] (p. 873) indicated that "a new way of thinking about systems has come to prominence" in the field of economics. Meadows [86] noted that trying to control complex systems would only lead to temporary solutions, requiring complexity thinking.

Utilizing complexity theory in instances where GST does not work well, as identified in the current article, better positions scholars and scholar-practitioners with the tools to address today's complex and wicked problems. This effort better prepares social scientists to explain observations of interactions and relationships in today's complex environment, providing them with the skills necessary to complete in the global business realm [9]. Remaining competitive in the 21st century requires a discipline to become innovative and adaptive as the "bar keeps rising" [73] (p. 1).

Within the literature presented, organizations can be reviewed to determine their functionality by incorporating CAS [22,28,29,37,53,87]. Additionally, leadership (e.g., leader–follower, adaptive leadership, and complexity leadership theory) has been associated with complexity theory and CAS [28,45,70,88], along with higher education [1] and organizational learning [26,34], among others. Also, complexity theory has already been applied to a variety of disciplines: "knowledge management, strategy, management, training, cultural change . . . . leadership, customer relationship management, and supply chain management" [79] (p. 467). Unfortunately, many disciplines within the social sciences have yet to begin investigations through the lens of complexity theory. It will become critical for today's leaders to begin thinking along the lines of complexity theory. Future scholars and scholar-practitioners will need to think and act differently [87] when facing complexity. Adopting complexity theory for the social sciences can aid the field in addressing tomorrow's problems when investigating social systems:

> Complexity is poised to help current and future leaders make sense of advanced technology, globalization, intricate markets, cultural change, and much more. In short, the science of complexity can help all of us address the challenges and opportunities we face in a new epoch of human history. [87] (p. Understanding Complexity)

**Author Contributions:** Conceptualization, J.R.T. and R.M.B.; methodology, J.R.T. and R.M.B.; investigation, J.R.T. and R.M.B.; data curation, J.R.T. and R.M.B.; original draft preparation, J.R.T. and R.M.B.; and review and editing of the final manuscript, J.R.T. and R.M.B.

**Funding:** This research received no external funding.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## References

1. Davis, A.P.; Dent, E.; Wharff, D. A conceptual model of systems thinking leadership in community colleges. *Syst. Pract. Act. Res.* **2015**, *28*, 333–353. [CrossRef]
2. Tong, Y.K.; Arvey, R. Managing complexity via the competing values framework. *J. Manag. Dev.* **2015**, *34*, 653–673. [CrossRef]
3. Ma, A.M.J.; Osula, B. The Tao of complex adaptive systems (CAS). *Chin. Manag. Stud.* **2011**, *5*, 94–110. [CrossRef]
4. deMattos, P.; Miller, D.; Park, E. Decision making in trauma centers from the standpoint of complex adaptive systems. *Manag. Decis.* **2012**, *50*, 1549–1569. [CrossRef]
5. Aritua, B.; Smith, N.; Bower, D. Construction Client multi-projects—A complex adaptive systems perspective. *Int. J. Proj. Manag.* **2009**, *27*, 72–79. [CrossRef]
6. Gregory, A.; Atkins, J.P.; Burdon, D.; Elliott, M. A problem structuring method for ecosystem-based management: The DPSIR modelling process. *Eur. J. Oper. Res.* **2013**, *227*, 558–569. [CrossRef]
7. Westhorp, G. Using complexity-consistent theory for evaluating complex systems. *Evaluation* **2012**, *18*, 405–420. [CrossRef]
8. Haslberger, A. The complexities of expatriate adaptation. *Hum. Resour. Manag. Rev.* **2005**, *15*, 160–180. [CrossRef]
9. Yawson, R.M. Systems theory and thinking as a foundational theory in human resource development—A myth or reality? *Hum. Resour. Dev. Rev.* **2013**, *12*, 53–85. [CrossRef]
10. Kast, F.E.; Rosenzweig, J.E. General system theory: Applications for organization and management. *Acad. Manag. J.* **1972**, *15*, 447–465. [CrossRef]
11. von Bertalanffy, L. The history and status of general systems theory. *Acad. Manag. J.* **1972**, *15*, 407–426. [CrossRef]
12. Caws, P. General systems theory, its past and potential. *Syst. Res. Behav. Sci.* **2015**, *32*, 514–521. [CrossRef]
13. Gilley, J.; Eggland, S.; Gilley, A.M. *Principles of Human Resource Development*, 2nd ed.; Basic Books: New York, NY, USA, 2002; ISBN 9780738206042.
14. Swanson, R.A.; Holton, E., III. *Foundations of Human Resource Development*; Berrett-Koehler: San Francisco, CA, USA, 2001; ISBN 1442961961.

15. Schneider, M.; Somers, M. Organizations as complex adaptive systems: Implications of complexity theory for leadership research. *Leadersh. Q.* **2006**, *17*, 351–365. [CrossRef]
16. Wang, T.-W. From general system theory to total quality management. *J. Am. Acad. Bus. Camb.* **2004**, *4*, 394–400.
17. Koopmans, M. Perspectives on complexity, its definition and applications in the field. *Complicity* **2017**, *14*, 16–35. [CrossRef]
18. Hammond, D. Ludwig von Bertalanffy (1901–1972): General systems theory. In *The Science of Synthesis: Exploring the Social Implications of General Systems Theory*; University Press of Colorado: Boulder, CO, USA, 2010; pp. 103–142, ISBN 1457109875.
19. Richardson, K. Systems theory and complexity: Part 2 [Forum]. *Emerg. Complex. Organ.* **2004**, *6*, 77–82.
20. Yorks, L.; Nicolaides, A. A conceptual model for developing mindsets for strategic insight under conditions of complexity and high uncertainty. *Hum. Resour. Dev. Rev.* **2012**, *11*, 182–202. [CrossRef]
21. Larson, C.S. Evidence of shared aspects of complexity science and quantum phenomena. *Cosm. Hist. J. Nat. Soc. Philos.* **2016**, *12*, 160–171.
22. Aagaard, P. The challenge of adaptive capability in public organizations: A case study of complexity in crime prevention. *Public Manag. Rev.* **2012**, *14*, 731–746. [CrossRef]
23. Albert, D.; Kreutzer, M.; Lechner, C. Resolving the paradox of interdependency and strategic renewal in activity systems. *Acad. Manag. Rev.* **2015**, *40*, 210–234. [CrossRef]
24. Anderson, A.; Dodd, S.D.; Jack, S. Entrepreneurship as connecting: Some implications for theorising and practice. *Manag. Decis.* **2012**, *50*, 958–971. [CrossRef]
25. Pslek, P.E. Some Emerging Principles for Managers of Complex Adaptive Systems. 1995. Available online: http://www.directedcreativity.com/pages/ComplexityWP.html (accessed on 20 November 2011).
26. Antonacopoulou, E.; Chiva, R. The social complexity of organizational learning: The dynamics of learning and organizing. *Manag. Learn.* **2007**, *38*, 277–295. [CrossRef]
27. Sherman, H.J.; Schultz, R. *Open Boundaries: Creating Business Innovation Through Complexity*; Da Capo Press: Reading, MA, USA, 1998; ISBN 0738201553.
28. Beck, T.; Plowman, D.A. Temporary, emergent interorganizational collaboration in unexpected circumstances: A study of the Columbia space shuttle response effort. *Organ. Sci.* **2016**, *25*, 1234–1252. [CrossRef]
29. Boal, K.B.; Schultz, P.L. Storytelling, time, and evolution: The role of strategic leadership in complex adaptive systems. *Leadersh. Q.* **2007**, *18*, 411–428. [CrossRef]
30. Bode, C.; Wagner, S.M. Structural Drivers of upstream supply chain complexity and the frequency of supply chain disruptions. *J. Oper. Manag.* **2015**, *36*, 215–228. [CrossRef]
31. Borzillo, S.; Kaminska-Labbe, R. Unravelling the dynamics of knowledge creation in communities of practice though complexity theory lenses. *Knowl. Manag. Res. Pract.* **2011**, *9*, 353–366. [CrossRef]
32. Bovaird, T. Emergent strategic management and planning mechanisms in complex adaptive systems—The case of the UK best value initiative. *Public Manag. Rev.* **2008**, *10*, 319–340. [CrossRef]
33. Waldrop, M. *Complexity: The Emerging Science at the Edge of Order and Chaos*; Penguin: Harmondsworth, UK, 1994; ISBN 9780671872342.
34. Chiva, R.; Ghauri, P.; Alegre, J. Organizational learning, innovation and internationalization: A complex system model. *Br. J. Manag.* **2014**, *25*, 687–705. [CrossRef]
35. Crawford, C.; Kreiser, P. Corporate entrepreneurship strategy: Extending the integrative framework through the lens of complexity science. *Small Bus. Econ.* **2015**, *45*, 403–423. [CrossRef]
36. Foster, J. From simplistic to complex systems in economics. *Camb. J. Econ.* **2005**, *29*, 873–892. [CrossRef]
37. Hammer, R.J.; Edwards, J.S.; Tapinos, E. Examining the strategy development process through the lens of complex adaptive systems theory. *J. Oper. Res. Soc.* **2012**, *63*, 909–919. [CrossRef]
38. Hanseth, O.; Lyytinen, K. Design theory for dynamic complexity in information infrastructures: The case of building internet. *J. Inf. Technol.* **2010**, *25*, 1–19. [CrossRef]
39. He, Z.; Rayman-Bacchus, L.; Wu, Y. Self-organization of industrial clustering in a transition economy: A proposed framework and case study evidence from China. *Res. Policy* **2011**, *40*, 1280–1294. [CrossRef]
40. Levy, S. *Artificial Life: The Quest for a New Creation*; Penguin Sciences Series: New York, NY, USA, 1993; ISBN 9780679743897.
41. Hearnshaw, E.J.S.; Wilson, M.M.J. A complex network approach to supply chain network theory. *Int. J. Oper. Prod. Manag.* **2013**, *33*, 442–469. [CrossRef]

42. Bradbury, R.H. Futures, predictions and other foolishness. In *Complexity and Ecosystem Management: The Theory and Practice of Multi-Agent Simulations*; Janssen, M.A., Ed.; Edward Elgar: Cheltenham, UK, 2002; pp. 48–62, ISBN 178195724X.
43. Holland, J. Complex adaptive systems. *Daedalus* **1992**, *121*, 17–30.
44. Honebein, P.C. Transmergent learning and the creation of extraordinary educational experiences. *Educ. Technol.* **2009**, *49*, 27–34.
45. Hunt, J.G.; Osborn, R.N.; Boal, K.B. The architecture of managerial leadership: Stimulation and channeling of organizational emergence. *Leadersh. Q.* **2009**, *20*, 503–516. [CrossRef]
46. Jones, R.; Corner, J. Seeing the forest and the trees: A complex adaptive systems lens for mentoring. *Hum. Relat.* **2012**, *65*, 391–411. [CrossRef]
47. Lauser, B. Post-merger integration and change processes from a complexity perspective. *Balt. J. Manag.* **2010**, *5*, 6–27. [CrossRef]
48. Lindberg, C.; Schneider, M. Combating infections at Maine Medical Center: Insights into complexity-informed leadership from positive deviance. *Leadership* **2013**, *9*, 229–253. [CrossRef]
49. Luoma, M. A play of four arenas—How complexity can serve management development. *Manag. Learn.* **2006**, *37*, 101–123. [CrossRef]
50. Waddock, S.; Meszoely, G.M.; Waddell, S.; Dentoni, D. The complexity of wicked problems in large scale change. *J. Organ. Chang. Manag.* **2015**, *28*, 993–1012. [CrossRef]
51. Rhodes, M.L. Complexity and emergence in public management—the case of urban regeneration in Ireland. *Public Manag. Rev.* **2008**, *10*, 361–379. [CrossRef]
52. Kelly, S.; Alison, M.A. *The Complexity Advantage*; McGraw-Hill: New York, NY, USA, 1999; ISBN 0070014000.
53. Strathern, M.; McGlade, J. *The Social Face of Complexity Science: A Festschrift for Professor Peter M. Allen*; Emergent Publications: Litchfield, AZ, USA, 2014; ISBN 9781938158131.
54. Campbell-Hunt, C. Complexity in practice. *Hum. Relat.* **2007**, *60*, 793–823. [CrossRef]
55. Mowles, C. Complex, but not quite complex enough: The turn to the complexity sciences in evaluation scholarship. *Evaluation* **2014**, *20*, 160–175. [CrossRef]
56. Martin, J.A.; Eisenhardt, K.M. Rewiring: Cross-business-unit collaboration in multibusiness organizations. *Acad. Manag. J.* **2010**, *53*, 265–301. [CrossRef]
57. Butler, M.J.R.; Allen, P.M. Understanding policy implementation processes as self-organizing systems. *Public Manag. Rev.* **2008**, *10*, 421–440. [CrossRef]
58. Burgelman, R.A.; Grove, A.S. Let chaos reign, then rein in chaos-repeatedly: Managing strategic dynamics for corporate longevity. *Strat. Manag. J.* **2007**, *28*, 965–979. [CrossRef]
59. Manuj, I.; Sahin, F. A model of supply chain and supply chain decision-making complexity. *Int. J. Phys. Distrib. Logist. Manag.* **2011**, *41*, 511–549. [CrossRef]
60. Gleick, J. *Chaos: Making a New Science*; Penguin Books: New York, NY, USA, 2008; ISBN 0143113453.
61. Richardson, K. Systems Theory and Complexity: Part 1 [Forum]. *Emerg. Complex. Organ.* **2004**, *6*, 75–79.
62. Bolstorff, P.A. Supply chain: A framework for expanding the human resource development professional's role in technology implementations. *Adv. Dev. Hum. Resour.* **2002**, *4*, 533–549. [CrossRef]
63. Hamstra, C. Complexity storytelling: The science of complexity within the art of communication. *Emerg. Complex. Organ.* **2017**, *19*, 1–6.
64. Plowman, D.A.; Baker, L.T.; Beck, T.E.; Kulkarni, M.; Solansky, S.T.; Travis, D.V. Radical change accidentally: The emergence and amplification of small change. *Acad. Manag. J.* **2007**, *50*, 515–543. [CrossRef]
65. Raisio, H.; Lundström, N. Managing chaos: Lessons from movies on chaos theory. *Adm. Soc.* **2017**, *49*, 296–315. [CrossRef]
66. Richardson, K. Managing complex organizations: Complexity thinking and the science and art of management. *Emerg. Complex. Organ.* **2008**, *10*, 13–26. [CrossRef]
67. Holte, J. *Chaos: The New Science*; University Press of America: Lanham, MD, USA, 1993; ISBN 9780819189332.
68. Jacobs, R. System theory and HRD. In *Handbook of Human Resource Development*; Chalofsky, N., Rocco, T., Morris, M.L., Eds.; Wiley: Hoboken, NJ, USA, 2014; ISBN 1118839897.
69. Proches, C.G.; Bodhanya, S. Exploring stakeholder interactions through the lens of complexity theory: Lessongs from the sugar industry. *Qual. Quant.* **2015**, *49*, 2507–2525. [CrossRef]
70. Uhl-Bien, M.; Marion, R. Complexity leadership in bureaucratic forms of organizing: A meso model. *Leadersh. Q.* **2009**, *20*, 631–650. [CrossRef]

71. Richardson, K.A. *Thinking about Complexity: Grasping the Continuum through Criticism and Pluralism*; Emergent Publishing: Litchfield Park, AZ, USA, 2010; ISBN 0984216456.
72. Waldrop, M.M. *Complexity: The Emerging Science at the Edge of Order and Chaos*; Simon & Schuster Paperbacks: New York, NY, USA, 1992; ISBN 0671767895.
73. Goldstein, J.; Hazy, J.; Lichtenstein, B. *Complexity and the Nexus of Leadership: Leveraging Non-Linear Science to Create Ecologies of Innovation*; Palgrave Macmillan: New York, NY, USA, 2010; ISBN 0230107710.
74. Rogers, S.M.; Tamkee, P.; Summers, B.; Balabahadra, S.; Marks, M.; Kingsley, D.M.; Schluter, D. Genetic signature of adaptive peak shift in threespine stickleback. *Evolution* **2012**, *66*, 2439–2450. [CrossRef]
75. McCall, R.; Burge, J. Untangling wicked problems. *Artif. Intell. Eng. Des. Anal. Manuf.* **2016**, *30*, 200–210. [CrossRef]
76. Xiang, W.-N. Working with wicked problems in socio-ecological systems: Awareness, acceptance, and adaptation [Editorial]. *Landsc. Urban Plan.* **2013**, *110*, 1–4. [CrossRef]
77. Head, B.W.; Alford, J. Wicked problems: Implications for public policy and management. *Adm. Soc.* **2015**, *47*, 711–739. [CrossRef]
78. Roberts, N. Wicked problems and network approaches to resolution. *Int. Public Manag. Rev.* **2000**, *1*, 1–19.
79. Kurtz, C.F.; Snowden, D.J. The new dynamics of strategy: Sense-making in a complex and complicated world. *IBM Syst. J.* **2003**, *42*, 462–483. [CrossRef]
80. Jayanti, E.B. Through a different lens: A survey of linear epistemological assumptions underlying HRD models. *Hum. Resour. Dev. Rev.* **2011**, *10*, 101–114. [CrossRef]
81. Scott, J. *Social Network Analysis: A Handbook*; SAGE: Thousand Oaks, CA, USA, 2000; ISBN 0761963391.
82. Richardson, K. Systems theory and complexity: Part 3 [Forum]. *Emerg. Complex. Organ.* **2005**, *7*, 104–114. [CrossRef]
83. Porter, T.; Reischer, R. We can't get here from there: Sustainability from complexity vs. conventional perspectives. *Emerg. Complex. Organ.* **2018**, *1*, 1–8. [CrossRef]
84. Tkachenko, O.; Ardichvili, A. Cultural-historical activity theory's relevance to HRD: A review and application. *Hum. Resour. Dev. Rev.* **2017**, *16*, 135–157. [CrossRef]
85. Chandler, J.; Rycroft-Malone, J.; Hawkes, C.; Noyes, J. Application of simplified Complexity Theory concepts for healthcare social systems to explain the implementation of evidence into practice. *J. Adv. Nurs.* **2016**, *72*, 461–480. [CrossRef] [PubMed]
86. Meadows, D.H. *Thinking in Systems: A Primer*; Chelsea Green Publishing: White River Junction, VT, USA, 2008; ISBN 978-1-6035-8148-6.
87. Snowden, D.; Boone, M. A leader's framework for decision making. *Harv. Bus. Rev.* **2007**, *85*, 68–76. [PubMed]
88. Uhl-Bien, M.; Marion, R.; McKelvey, B. Complexity leadership theory: Shifting leadership from the industrial age to the knowledge era. *Leadersh. Q.* **2007**, *18*, 298–318. [CrossRef]