Systems Thinking in Environmental Health and Public Health

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Summer EH

Overview
1. What are wicked problems?
2. What are systems thinking and its tools?
3. What are the key features of complex systems?
4. What are some systems analytical approaches?
5. What do these offer that is different from current public health and epidemiology approaches?
6. How should we intervene on environmental health problems?

“Wicked* Problems” Idea first appeared in 1970s

- No clear problem definition; complete diagnosis or understanding not possible; each perspective from which problem viewed gives different understanding of its nature
  - Because cannot be directly observed, unpredictable, uncertain
  - Can be unstable (problem itself is moving target)
- Multi-causal, multi-scalar, inter-dependencies
  - An input spreads out, bounces around, echoes throughout system
- Many possible responses and many possible endpoints
  - No response is perfect or optimal
  - Responses don’t solve, have trade-offs
- Exist over long temporal scales, wait a long time to see what works
- Multiple stakeholders, usually socially complex
- Straddle organizational and disciplinary boundaries
- Have a history of policy failure
  - Policy makers often artificially bound problem, make linear & unidirectional

* Very difficult to resolve, Rittel & Webber 1973

Systems Thinking

Past Responses to Environmental Health Problems

• Focus on symptoms of problems, not root causes
• Compartmentalized, pollutant-specific
• Overly simplified approaches
  – One hazard type (i.e., of our six hazards types) at a time
  – One exposure agent at a time
  – One medium at a time (e.g., air, water)
• Linear, unidirectional thinking between cause and effect
• Did not incorporate complexity, not multilevel, not multi-scalar
• Risk-based, with many assumptions, incomplete data

Why Are We Telling You About Systems Approaches?

• Public health problems are getting more difficult to solve, they are more commonly wicked
• Council on Education for Public Health (CePH, for accreditation) and Association of Schools of Public Health (ASPH) defining as public health competency
Systems Thinking

Capacities and Capabilities for Public Health Practitioners of Future

• **Systems thinking and system models**
  — Foundational to all other skills

• **Communication capacities and capabilities**
  — Public health-specific communication & social marketing, technical & professional writing, mass media, electronic technology

• **Entrepreneurial orientation**
  — Management, planning, budgeting, human resources, assessment, evaluation, organizational behavior, inter-professional collaboration

• **Transformational ethics**
  — Legal, ethical, economic, regulatory dimensions of health care and public health policy, multilevel causes of disease, human rights frameworks, structural bias and health disparities

• **Policy analysis and response**
  — Multiple dimensions of policy-making process, ethics and evidence, advocacy, evaluation, communication

  *AJPH* 2017, v107, p 1227

Systems Thinking Defined

• Barry Richmond 1987: “Art and science of making reliable inferences about behavior by developing an increasingly deep understanding of underlying structure.”

• Holistic approach to evaluating an issue; *conceptual* orientation

• Focuses on way a system’s constituent parts are inter-related (complexity), work and change over time (dynamics), and are related to functioning whole
  — **Change** over time is key; from chaos theory; butterfly effect and tipping point; makes long-term prediction difficult
  — System behavior results from reinforcing & balancing **feedbacks**

• Traditional approaches to analysis break problems down into separate, smaller elements (**reductionism** = linear, atomistic, mechanistic)

  *Trochim, AJPH* 2006; Searchcio.techtarget.com

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**Origins of Systems Thinking**

Largely developed in 20th century with many contributors & disciplines

- Ludwig von Bertalanffy: biologist – General System Theory
- Ross Ashby, psychiatrist; Gregory Bateson, anthropologist
  - Cybernetics: origins of system theory; study of communication & control of regulatory feedback (aka automatic control systems, biologic & engineered)
- Jay Forrester, computer engineer
  - Systems dynamics: an approach to understanding nonlinear behavior of complex systems using stocks, flows, feedback loops, time delays
- Gell-Mann and Arrow (Santa Fe Institute): complex adaptive systems
- Russell Ackoff, management thinker: operations research
- Peter Senge, management thinker
  - Learning organization theory: systems approach to understanding organizations, facilitate learning by members and continuous transformation
- Joshua Epstein, economist
  - Agent-based models: visual representations of complex systems; define interactions between agents with simple rules; emergence and self-organization are observed
- Defense & intelligence communities: VUCA = volatility, uncertainty, complexity, ambiguity


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In 1950s & 1960s, urban decay and problems it caused were challenging problem. Urban riots in Los Angeles, Newark, Detroit, DC; MLK assassinated; increasing crime; racial tensions; white flight; business flight; vicious cycle. Jay Forrester of MIT shares office with new visiting faculty, past mayor of Boston, John F. Collins, in 1968.

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**Systems Analysis as a Tool for Urban Planning**

JAY W. FORRESTER, FELLOW, IEEE

IEEE TRANSACTIONS ON SYSTEMS SCIENCE AND CYBERNETICS, VOL. SSC-6, NO. 4, OCTOBER 1970

"Results suggest most of today's popular urban policies lie between neutral & detrimental in effectiveness."

Our understanding of how & why urban areas evolve: wrong.
Another Early Jay Forrester model: The World Model for The Club of Rome (with Donella Meadows)

- Was asked: how are major global problems – poverty and hunger, environmental destruction, resource depletion, urban deterioration, unemployment – related and how might they be solved?
- Forrester’s model showed that growth was the problem, population & economic
- Economic growth: the very thing that politicians are trying to promote

"If present growth trends in world population, industrialization, pollution, food production, and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years."

Applications to Public Health

- Many public health problems (e.g., obesity) have been resistant to understanding causes and developing interventions using past approaches
- The health of a population is a complex adaptive system
- Complexity theory has had many early successes applied to public health and should be used more

- Factors can exist at many levels, from molecular to behavioral, social, environmental, and policy
- Factors can influence one another and be influenced by health, with dynamic feedbacks and changes over time
- Advocate a shift to complex systems dynamic approaches that incorporate these complexities

- “Patterns of population health outcomes are an emergent property of the system. They arise from a web of causations that result from interactions among dynamic sets of interconnected systems.”
How to Address Public Health Problems?

… and what works?

(Rutter Lancet 2017)

Traditional approach to public health intervention evaluation
- Descendants of methods used to evaluate clinical interventions
  - Linear models of cause & effect
  - Require randomization, comparison groups, covariate control
  - One factor at a time, control others
  - Often aimed at individuals and not in circumstances in which they live

Complex system approach to evaluation
- Health and health inequalities are outcomes of a multitude of interdependent elements within a connected whole
- Allows a wider set of approaches, and emergence, feedback, adaptation
- Cannot generally be resolved with single interventions; no “fixing” of problems
- Complex, multiple, upstream, population-level actions and outcomes
- Does intervention contribute to reshaping system in favorable ways, at multiple levels and over long time periods?
What is a Complex System?

• “One whose properties are not fully explained by an understanding of its component parts” (Gallagher R, Appenzeller T. *Beyond reductionism*. *Science* 1999)
• The system’s components and feedback loops cause its behavior (Meadows 2008; Mitchell 2009)
• The interactions produce an *emergent* effect that is different from the effects of the individual elements
• Effect persists over time, *adapts to changing circumstances* (e.g., tobacco company reduces prices in response to increased taxes)
• The interesting and important part of a system is its *emergent behavior*, so cannot decompose it

Characteristics of a System

• System is composed of parts (*elements*)
• Parts are *interconnected* through feedback loops
• Elements and connections are system’s *structure*
• Structure determines *behavior*
• Behavior *emerges* from its key feedback loops over time
  - Meadows: system behavior is “function” (nonhuman) or “purpose” (human)
    - Deduced from behavior, not rhetoric or stated goals
  - *What is purpose of U.S. food, community socioeconomic, and built environment systems?*
Is it a System? Or a Bunch of Stuff?

1. **Elements**
   - Typically most obvious part of dynamic system
   - Changing elements often has little effect on system behavior

2. **Interconnections**
   - Often involve the flow of information
   - Changing connections usually changes system behavior

3. **Function or purpose**
   - Often least obvious part of a dynamic system – emergent property
   - Determined by observing a system’s behavior
   - System behavior reveals itself as a series of events over time

- Can you identify individual parts?
- Do the parts affect each other?
- Do the parts together produce an effect that is different from the effect of each part on its own?
- Does the effect persist in a variety of circumstances?

Adapted from P. Woessner and J. Beltowska

**Traditional analysis** focuses on individual pieces of what is being studied
- Isolates smaller and smaller parts of what is under study

**Systems thinking** focuses on how the things under study interact with other constituents of the system.
- Expands view to consider larger and larger numbers of interactions as an issue is under study

“System thinking has a long history, but is far from an established field. There are no systematic overviews on the use of systems approaches in the public sector, and the process used in practice is not formalized. Furthermore, little empirical research has been done on the strategies policy makers use to deal with uncertainty in practice.”

OECD (2017), *Systems Approaches to Public Sector Challenges: Working with Change*
Emergence

“Arising of novel and coherent structures, patterns, & properties during process of self-organization* in complex systems.”

*Social sciences refer to as spontaneous order; chaos theory as “predictability in sea of chaotic unpredictability”

Occurs in many physical, chemical, biological, robotic, cognitive, and social systems

Examples: ecosystems, Internet, crystallization, groupthink, herd behavior

Common properties of emergent phenomena:

- **Radical novelty**: not previously observed in the complex system under observation; neither predictable nor deducible
- **Coherence**: appear as integrated wholes that tend to maintain identity over time; the separate lower-level components form a higher-level unity
- **Macro level**: emergents are behaviors usually at the macro level
- **Dynamical**: arise as system evolves over time
- **Ostensive**: emergents are recognized by showing themselves

Goldstein J. *Emergence* 1999.

Examples of Emergence

- Group of starlings + desire to avoid collision + desire to stay close to neighbors → complex behavior of flying flock
- Wind + humidity + evaporation + Coriolis effect → hurricane
- Sand + wind + small obstructions → sand dunes
- Food system + land use + social environment + health care system → U.S. obesity epidemic
- People + places + culture → city, self-organized into neighborhoods

www.evolutionofcomputing.org; www.pbs.org/wgbh/nova
We Use Mindsets & Models

- We try to understand the world: we make observations and then inferences
- We assemble ideas into mental models
- Everything we think we know about the world is a model
- Our models have a strong congruence with the world (otherwise we change them)
- This provides us with confidence that we understand the world
- Models never fully represent the real world

“Thinking consists of two activities: constructing mental models and then simulating them in order to draw conclusions and make decisions.” – Barry Richmond (U.S. systems scientist)

“All models are wrong, but some are useful.” – George Box (Professor of Statistics)

The Iceberg Model

Four levels of thinking

- Events: What just happened? React
  - I caught a cold.
- Patterns/trends: What trends have there been over time? Anticipate
  - I’ve been catching more colds when sleeping less.
  - I have more stress at school, not eating well, & difficulty accessing healthy food near home or school.
- Mental models: What assumptions, beliefs, and values do I hold about the system? What beliefs keep the system in place? Transform
  - Education and career are the most important piece of identity, healthy food is too expensive, rest is for the unmotivated.

www.nwei.org
Albert Einstein: “The problems we have created in the world today will not be solved by the level of thinking that created them.”

How do Complex Systems Behave?

- Uncertainty
- Unpredictability
- Delays and lags
- Non-linear
- Stocks and flows characteristics
- Inter-connected, tightly coupled, adaptive & evolving
- A trade-off between optimality and resilience (to optimize performance generally remove redundancy)
- Tipping points – unknown until breached
- Feedbacks, oscillating, self-organizing, counterintuitive (cause & effect distant in space & time)
- Have multiple possible equilibrium states – some hostile to human needs and purposes
- Emergent properties – appearance of new features that were not predictable at start

Systems Thinking Tools

<table>
<thead>
<tr>
<th>Tool</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rich pictures</td>
<td>Learning about complex problems by drawing detailed representations using pictures &amp; symbols</td>
</tr>
<tr>
<td>Causal loop diagrams</td>
<td>Qualitative illustrations of mental models, focused on causality and feedback loops; expand to include measurement variables quantitatively</td>
</tr>
<tr>
<td>System archetypes</td>
<td>Tools that describe common behaviors across many types of systems</td>
</tr>
<tr>
<td>Scenario planning</td>
<td>To identify and analyze potential future events and alternatives, qualitatively or quantitatively</td>
</tr>
<tr>
<td>Stakeholder analysis</td>
<td>For producing knowledge about actors to understand behavior, intentions, relationships, &amp; interests; also used to assess actors’ influence &amp; resources on decision-making or implementation</td>
</tr>
<tr>
<td>MSD* &amp; CBM**</td>
<td>Structured, interactive process that brings relevant stakeholders together to create mutual understanding and shared courses of action</td>
</tr>
<tr>
<td>Also stock &amp; flow diagrams; process mapping; participatory impact pathways analysis; innovation/change management history</td>
<td></td>
</tr>
</tbody>
</table>

*Multi-stakeholder dialogue, consensus-building methods

Sustainability in Vietnam – Causal Loop Diagram


Global Public Health, 2018, v13, p 1287

Four archetype stories
1. Limits to growth
2. Fixes that fail
3. Tragedy of the commons
4. Shifting the burden

www.atkisson.com

= delay
Related systems tool: fault tree mapping and modeling

**Assessing food system vulnerability**
*BMC Public Health 2018*

- Food present but barriers prevent acquisition by community
- Food not present at provisioning points
- Food is not safe, nutritious, or acceptable

**Significant disruption in provisioning of food such that community food security is threatened**

```
Food is not available
<table>
<thead>
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<tbody>
<tr>
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</table>
Food is not physically
  | acceptable
  |          |
  |          |
Food is not economically
  | acceptable
  |          |
  |          |
Food is not culturally
  | appropriates
  |          |
  |          |
Food is not medically
  | adequately
  |           |
  |           |
Food is not
  | nutritionally
  | adequate
  |          |
  |          |
Donation
  | failure
  |          |
  |          |
High food price
  |          |
  |          |
Significant
  | intervention
  |          |
  |          |
Unhealthy
  | diet
  |          |
  |          |
Driving forces
  | components
```

```
5 subtrees under here```

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Summary of Different Thinking Approaches: using the Cynefin Framework

(Cynefin: Welsh word, means habitat)
Early 2000s by IBM, conceptual framework to aid decision-making
Four different contexts: simple, chaotic, complex, complicated

Generalized principles to specific conclusion; “top down”; theory based; more deductive
Specific events to generalized conclusion; cause and effect, “bottom up” reasoning; inductive

Known knowns
Known unknowns
Unknown unknowns
Act first!
Stop the bleeding!

Art by Edwin Stoop (actually a system thinking tool = rich picture)

Move to Analysis: Traditional vs. Systems Analysis Approaches

<table>
<thead>
<tr>
<th>Domain</th>
<th>Traditional analytic techniques assumptions</th>
<th>Complex systems assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functional form</td>
<td>Linearity</td>
<td>Nonlinearity</td>
</tr>
<tr>
<td>Common distributions</td>
<td>Normality</td>
<td>Nonnormality</td>
</tr>
<tr>
<td>Characteristics of actors</td>
<td>Homogeneity</td>
<td>Heterogeneity</td>
</tr>
<tr>
<td>Level of analysis</td>
<td>Single level</td>
<td>Multiple levels</td>
</tr>
<tr>
<td>Temporality</td>
<td>Static or discretely longitudinal</td>
<td>Dynamic, with feedback</td>
</tr>
<tr>
<td>Fundamental relationships</td>
<td>Among variables</td>
<td>Interaction of actors</td>
</tr>
<tr>
<td>Perspective</td>
<td>Reductionist</td>
<td>Holistic</td>
</tr>
</tbody>
</table>

Also: independence vs. interdependence; feedbacks – no vs. yes; no connection between levels vs. emergence; adaptation and self-organization – no vs. yes

Three common quantitative methods (Luke 2012; Erwin 2017)

1. **System dynamics**: informal and formal models with computer simulation to uncover and understand endogenous sources of complex system behavior [stock, flow, feedback loops]
2. **Social network analysis**: measurement and analysis of relationships and flows among actors (e.g., people, organizations, other information processing entities)
3. **Agent-based modeling**: computer simulations examine how system elements (agents) behave as a function of interactions with each other and environment; “bottom up” approach; infectious diseases, epidemics, disease transmission
Systems Thinking

Systems Analysis Guidelines

• All models are simplifications of the real world
  — You decide how much detail to include
• There are no right answers
  — Mapping out a system allows you to see potential actions
  — As you become more proficient, you recognize consequences of different interventions
• Cause and effect will not be closely related in time a space
  — Don’t look for leverage points near the symptoms of the problem
• Good results depend on bringing in many perspectives
  — Make your system model more informed
• Use your intuition when working with archetypes
  — Is probably good enough as a starting point
• Look for multiple levels operating simultaneously

Adapted from P. Woessner and J. Beltowska

The Basics of Systems Dynamic Modeling

• We are limited in our ability to form and reform mental models
• Systems modeling allows us to move from “what” to “what if”
• These also allow us to make our thinking visible to others
• Basic building blocks: stocks, flows, and loops

Adapted from P. Woessner

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Stocks, Flows, Dynamic Equilibrium

- Stock: foundation of system and elements that can be seen, felt, counted, or measurable
  - Do not have to be physical
  - Stock is present memory of history of changing flows
    - Sum inflows > sum outflows, stock level rises
    - Sum outflows > sum inflows, stock level falls
    - Sum outflows = sum inflows, stock level in dynamic equilibrium
- Stocks act as delays, buffers or shock absorbers in system
- Stocks allow inflows & outflows to be de-coupled & independent

From D. Meadows

Feedback Loops

- Formed when changes in stock affect flows into or out of same stock
- Closed chain of causal connections from stock, through decisions / rules / physical laws / actions that are dependent on level of stock, and back again through flow to change stock
- Balancing feedback loops
  - Equilibrating or goal-seeking structures in systems
  - Sources of stability and sources of resistance to change
- Reinforcing feedback loops
  - Self-enhancing, leading to exponential growth or to runaway collapses over time
- Information delivered by feedback loop can affect only future behavior; cannot deliver signal fast enough to correct behavior
- Stock-maintaining balancing feedback loop must have its goal set appropriately to compensate for inflows and outflows to stock
- Similar feedback structures produce similar dynamic behaviors

From D. Meadows
Room temperature regulated by a thermostat and furnace

A one-stock system with two competing balancing loops

There can be shifting dominance and also delays of feedback loops. When one loop dominates the other it has a stronger influence on system behavior.

Shifting Dominance, Delays, Oscillations

- Complex behaviors of systems arise as relative strengths of feedback loops shift, causing first one loop and then another to dominate behavior
- A delay in balancing feedback loop makes a system likely to oscillate
- Changing length of delay may make large change in behavior of system

From D. Meadows
Economic capital with its reinforcing growth loop constrained by a non-renewable resource

Economic capital with its reinforcing growth loop constrained by a non-renewable resource

Constraints on Systems

- In physical, exponentially growing systems, must be at least one reinforcing loop driving growth and at least one balancing loop constraining growth
  - No system can grow forever in finite environment
- Nonrenewable resources are stock-limited
- Renewable resources are flow-limited

From D. Meadows
Systems Thinking

Source of System Surprises

• Relationships in systems can be nonlinear
• There are no separate systems. The world is a continuum. Where boundaries are drawn changes system behavior.
• At any given time, most limiting input is most important
• Physical entities with multiple inputs and outputs have many layers of limits
• There always will be limits to growth
• Exponentially growing quantities reach limits very rapidly
• When are long delays in feedback loops, foresight is essential
• Bounded rationality of each actor in system may not lead to decisions that further welfare of system as a whole

From D. Meadows

Conceptual Model: Key Determinants of Community Functioning (CF) after An Event (e.g., hurricane, tsunami, earthquake)

Term from CBRNE: programs, products, systems

Community functioning (CF) after event

EM = emergency management

CBRNE = chemical, biologic, radiologic, nuclear, explosive

Disaster Med Publ Health Prep 2018, v12, p 127
Places to Intervene in a Complex System
(Meadows 1999, 2008)

1. Constants, parameters, numbers
2. Size of buffers & stabilizing stocks
3. Structure of material stocks & flows
4. Length of delays
5. Strength of negative feedback loops
6. Gain around driving positive feedback loops
7. Structure of information flow
8. Rules of the system
9. Power to add, change, evolve, or self-organize system structure
10. Goals of the system
11. Paradigm that system arises out of
12. Power to transcend paradigms

• Look for leverage points
• Places within a complex system where a small shift in one thing can produce big changes in everything
• Leverage points: “points of power”
• Often we know what these are intuitively, but push in wrong direction – counterintuitive
• Example: politicians push growth to solve world’s problems, but growth is causing them → poverty, hunger, environmental degradation
• Example: Forrester’s urban dynamics study – reduce subsidized housing → improve employment, welfare costs

In ascending order of effectiveness and difficulty
### Examples of Intervention Points

<table>
<thead>
<tr>
<th>Intervene point</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numbers</td>
<td>Cap campaign spending; ambient air quality standards</td>
</tr>
<tr>
<td>Buffers</td>
<td>Invest in engineering to increase size of water reservoirs</td>
</tr>
<tr>
<td>Physical structure</td>
<td>Rebuild cities and transportation networks</td>
</tr>
<tr>
<td>Delays</td>
<td>Reduce time to new technologies</td>
</tr>
<tr>
<td>[-] feedback (↑)</td>
<td>FOIA for government secrecy, whistle blower protection, pollution taxes, strengthen democracy</td>
</tr>
<tr>
<td>[+ ] feedback (↓)</td>
<td>Slowing population growth, slowing economic growth (interest rates)</td>
</tr>
<tr>
<td>Structure information</td>
<td>TRI, emissions reporting, real-time feedback on energy use, specify on tax returns what your taxes can be used for</td>
</tr>
<tr>
<td>Rules</td>
<td>JHSPH faculty promoted based on solving real-world problems; U.S. President can serve 30 years</td>
</tr>
<tr>
<td>System structure; self-organizing</td>
<td>System changes itself; result of biologic, social, cultural, technological evolution; biological and cultural diversity represent self-organization</td>
</tr>
<tr>
<td>Goals</td>
<td>Corporation: from ↑ stockholder wealth → ↑ public good</td>
</tr>
<tr>
<td>Paradigm/mindset</td>
<td>Economic &amp; population growth are not good; no private land owners</td>
</tr>
<tr>
<td>Transcend</td>
<td>There are no paradigms and mindsets; extreme flexibility</td>
</tr>
</tbody>
</table>

*The lower on the list, the more the system will resist the change.*

### Skills for wicked problems

- Systems thinking
  - 14 habits (Waters Foundation)
  - How to involve and work with stakeholders
- Novel data sources
  - Electronic, mobile, remote sensing, commercial, from citizens, digital world around us
- Big data streams
- Data integration
- Computational models and skills
- Science translation to policy, careful decision-making
- Science communication
  - Numbers numb, stories sell
- Continuous monitoring, evaluation, and integration
**Systems Thinking**

**GLOSSARY: If you see these words, then systems thinking is being used …**

<table>
<thead>
<tr>
<th>Concept</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptable</td>
<td>Capacity of system to modify itself to adjust to changes in environment</td>
</tr>
<tr>
<td>Agent</td>
<td>Actor within a system</td>
</tr>
<tr>
<td>Capacity building</td>
<td>Human, scientific, technological, organizational, institutional, and resource capabilities. Enhances ability to evaluate and address implementation options, based on perceived potentials, limitations, and needs of system</td>
</tr>
<tr>
<td>Chaos</td>
<td>Small changes in initial conditions produce wildly different results</td>
</tr>
<tr>
<td>Collaboration</td>
<td>Different entities working together to create something</td>
</tr>
<tr>
<td>Dynamic</td>
<td>Systems adjust and readjust at many interactive time scales</td>
</tr>
<tr>
<td>Emergence</td>
<td>Spontaneous creation of order and functionality from the bottom up.</td>
</tr>
<tr>
<td>Feedback loops</td>
<td>Information that returns to original transmitter to influence subsequent actions</td>
</tr>
<tr>
<td>Holism</td>
<td>Properties of system cannot be determined / explained by components alone</td>
</tr>
<tr>
<td>Interdependent</td>
<td>Interactions among parts of system (also “interconnected”)</td>
</tr>
<tr>
<td>Linearity</td>
<td>Inputs lead to predictable outputs</td>
</tr>
<tr>
<td>Nonlinearity</td>
<td>System relationships cannot be arranged along simple input-output line</td>
</tr>
<tr>
<td>Self-organization</td>
<td>System dynamics arise spontaneously from internal structure</td>
</tr>
</tbody>
</table>

*J Eval Clin Pract 2018, v 24, p 607*

**References (others cited on individual slides)**