The Applications of Systems Science

Understanding How the World Works and How You Work In It

Motivating Question

- What does it mean to ***UNDERSTAND***?
  - Feeling of understanding – listening to a lecture or reading a book
  - Using understanding – solving a problem or creating an artifact
  - Understanding processes – predicting an outcome

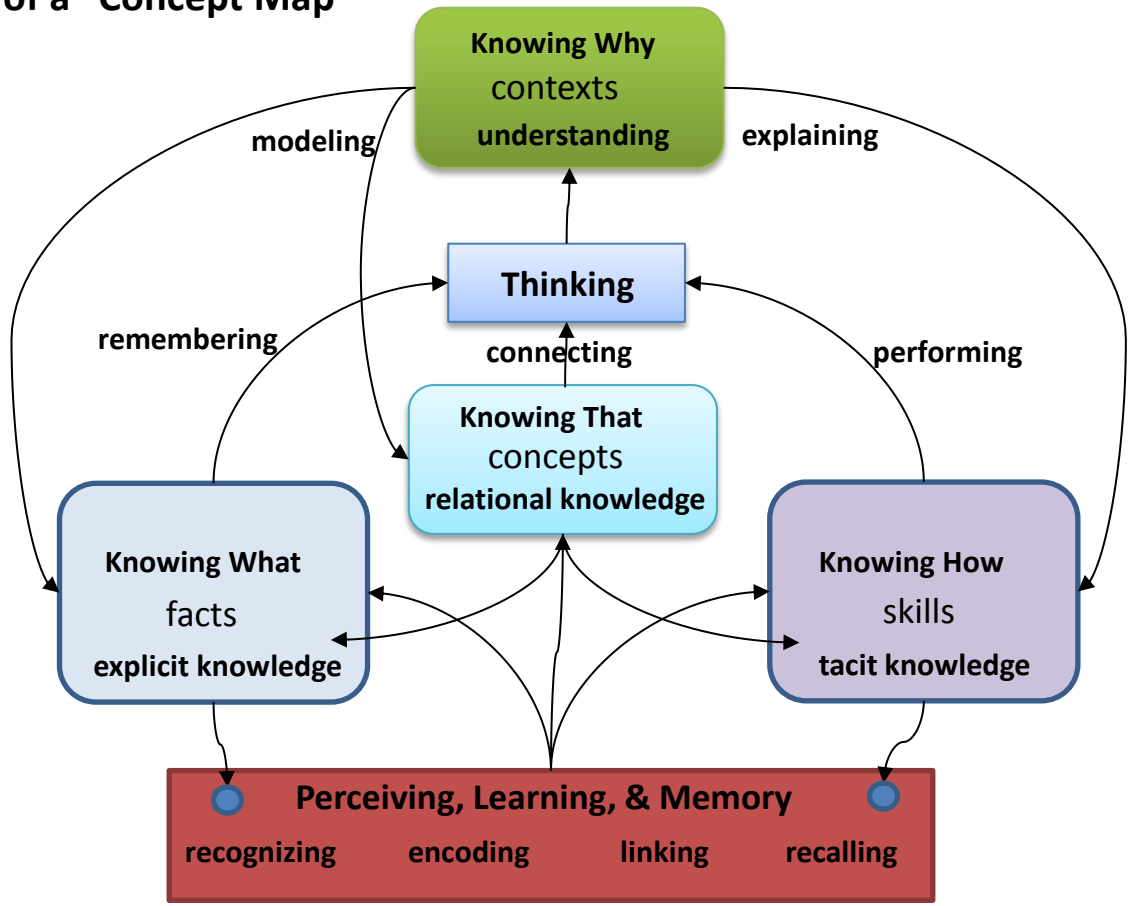
Understanding

- Various categories of what we call knowledge
  - ***Knowing What****: facts, explicit, episodic knowledge
    - Conscious remembering
  - ***Knowing How***: skills, tacit knowledge
    - Performance of tasks, reasoning
  - ***Knowing That***: concepts, relational knowledge
    - Connecting different concepts
  - ***Knowing Why***: contexts, ***understanding***
    - Modeling and explaining
- Thinking is the dynamics of the interactions between these various categories
- Competencies based on strength of cognitive capabilities

* Includes knowing when and where

The System of Knowledge and Knowing

An example of a "Concept Map"



Cognitive Capabilities

Thinking

- Thinking capabilities depend on general cognition models
  - Critical thinking
    - Skepticism, recognizing biases, evidence-based, curiosity, reasoning
  - Scientific thinking
    - Critical thinking + testing hypotheses, analyzing evidence, formal modeling
  - Systems thinking
    - Scientific thinking + holistic conceptualization, Universal patterns (principles)

Why Systems Science?

- ***Everything in the Universe is a system***
  - ***You are a system***
  - ***Your family, school, community, etc. are systems***
  - ***All things around you are systems or parts of systems***
  - ***The World is a system***
- All systems share common attributes, properties, and principles of organization and behavior
- Understanding these common or universal aspects is the basis for ***understanding*** anything!

Course Objectives

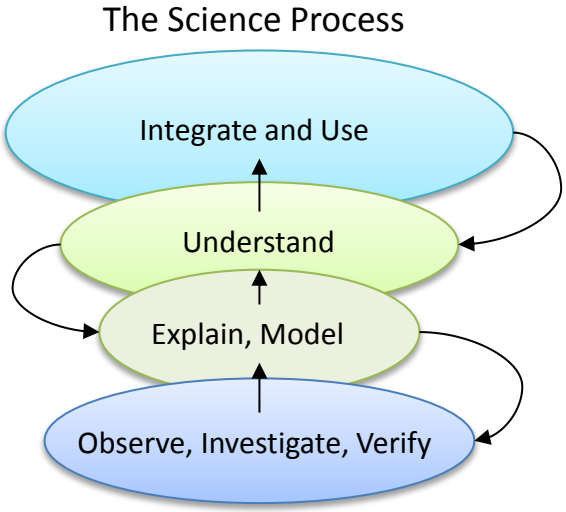
- The primary objective is to provide you with the basic concepts that
  - Allow you to understand various phenomena
  - Show you how everything you encounter is connected
  - Give you tools for thinking critically about multifarious subjects
- A secondary objective is to provide you with an intellectual environment where you can explore ideas

Course Outline

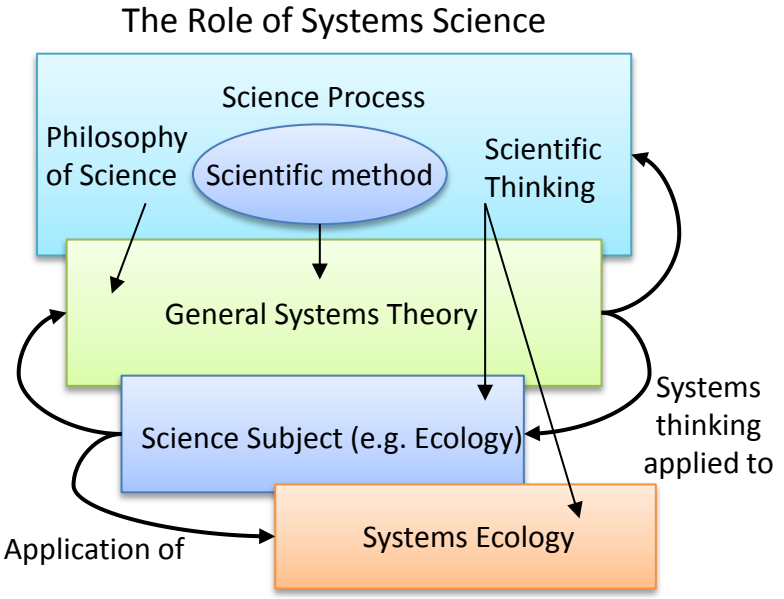
- Week 1: Introduction to Systems Science
- Week 2: Overview of Systemness
- Week 3: Principles of Organization, Networks, & Complexity
- Week 4: System Dynamics and Behavior
- Week 5: Information, Knowledge, & Computation
- Weeks 6 & 7: Cybernetics: the Science of Control & Management
- Week 8: Emergence and Evolution
- Week 9: Intentional Systems

Introduction to Systems Science

- Meta-science
- Systems science uses scientific thinking
- Systems science informs sciences



Evidence, hypothesize, experiment, analyze, review



The Concept of a System

- An identifiable whole – an entity or object
  - bounded in some way
- Interacts with its environment in various ways
  - Inputs/Outputs (matter, energy, messages)
- Has internal organization
  - Composed of many component parts
  - Processes inputs to produce outputs
- Subject to change over time
  - Growth, development, decay, dissolution
  - Sufficiently complex systems can be adaptive

Systems Thinking Applied

- Understanding a “thing” and/or a phenomena as a system gives greater insights
- Using systems principles to guide scientific investigations
- Science tends to be *reductionist*
- Systems thinking tends to be *integrative*, *holistic*
- Combining the two approaches
- Building models of systems

Formal Systems Science

- Early science focused on the successes obtained from reductionism – taking things apart
- Evolved to categorization – identification of similar/unlike things
- Evolved further to explanation of causes
- Systems thinking in the background in all sciences
- Methods of science applied to systemness itself
- Systems science has started to pervade all sciences

How Systems Science Works

- Survey ***models*** of specific systems, e.g. biological systems such as cells and organisms or social systems such as communities
- Seek ***commonalities*** in terms of explanations of how systems ***function*** and ***evolve***
- Use ***analytical methods*** to find those commonalities
- Develop ***languages*** that can describe all systems regardless of specific domains, e.g. whether biological or physical
- Develop general principles that provide ***causal explanations*** regardless of the details of any specific system
- Develop ***mathematical*** descriptions of those principles such that they can be employed to discover new aspects of specific systems

A Conceptual History of Science and Systems Science

- Psychology of causal thinking – built into our brains
- Backward causal relations to find explanations of why and how things happen – abductive reasoning
- First tentative scientific process came with control over fire and really took off with invention of agriculture – Became formalized with civilizations
- Inquiry:
  - What is inside? ⟶ Reductionism
  - How does this work? ⟶ Mechanism
  - Why does this happen? → Explanation → Understanding

General Systems Theory

- Every identifiable object is a system of some kind
  - Simple vs. Complex
- All systems share properties (principles) that govern their form and function
- A scientific approach to the study of systemness can provide guidance in the study of specific kinds of systems, e.g. biological systems (systems biology)

Universal Principles of Systems Science

- Here are a set of principles that have been discovered to operate over all knowledge domains
  1. Systemness – the world is composed of systems of systems
  2. Systems are organized in structural and functional hierarchies
  3. Systems are networks of interactions between components and can be represented as abstract networks of relations between them
  4. Systems are dynamic processes on one or more time scales
  5. Systems exhibit various kinds and levels of complexity
  6. Systems can encode knowledge and receive and send information

  For complex adaptive systems (CASs)

  7. Systems emerge from proto-systems (unorganized, not complex) and evolve over time to greater organization and complexity
  8. Systems have internal regulation subsystems to achieve stability

Additional Principles for Complex Adaptive Systems (CAS)

- Several principles related to systems thinking, systems science, and systems development

9. Systems can contain models of other systems
10. Sufficiently complex, adaptive systems can contain models of themselves (brains and mental models)
11. Systems can be understood (a corollary of #9) – Science as the building of models
12. Systems can be improved (a corollary of #6) – Engineering as an evolutionary process

Native Systems Cognition

- Every animal with a cerebral cortex has a built-in capacity to encode memories as systems
- Humans have the added capacity to work with system concepts abstractly
- Thinking in systems is natural but is almost always limited to local scales of time and space
- One piece of evidence that our brains naturally process systemness...

“THING” – The Most Useful Word in any Language!

- ***Native*** (informal) systems thinking
- “Thing” is a placeholder word for objects, or relations that are not yet described or defined
- We naturally ascribe systemness to something we call a thing because we understand that every***thing*** is a system even if we don’t completely understand it
- We use “curiosity” about a thing to delve more deeply to gain understanding

Seminar Questions – Intro to Systems Science

- What are the major differences between the categories of knowledge?
- Why do those differences exist?
- How do they work together to produce cognition?
- Why do we call systems science a “meta-science?”
- Why is systems science a science in the classical sense?
- How is it different from classical (before ~ 1950) sciences?
- How has it impacted the sciences over the last 3-4 decades?
- Why are the outlined principles said to be Universal?
- Why do we claim human beings naturally think systemically? Why do you think this native systems thinking is weak?