Supplementary Notes: (PJ Shlachtman, Miller book)

Critical Thinking: Science, Models and Systems

Science, Technology, and Environmental Science

Science is a pursuit of knowledge about how the world works, an attempt to discover order in nature and use that knowledge to make predictions.

Scientific data (or facts) are used to make observations and solve problems.

Experiment - a procedure a scientist uses (in lab or in nature) to study some phenomenon.

Reproducibility is important in science to detect errors in experimentation.

Scientific Hypothesis (a testable statement) is a possible explanation for a particular observation

A **model** is an approximate representation or simulation of a system being studied and may be used to test a hypothesis. Models include:

- **Mental** - perceive the world, control their bodies and think about things
- **Conceptual** - describe the general relationships among components of a system
- **Graphic** - compile and display data in meaningful patterns (map)
- **Physical** - try out designs and ideas (scale models of airplanes, buildings)
- **Mathematical** - consist of one or more mathematical equations to describe the behavior of a system (rule of 70).

Data is subject to **review** by other scientists and usually falls into this pattern:
observe---> hypothesize---> argue---> test---> hypothesize---> argue---> test

A **scientific theory** is an idea, principle, or model that usually ties together and explains many facts that previously appeared to be unrelated and is supported by a great deal of evidence. (Big Bang Theory, John Dalton- Atomic Theory of Matter- all matter is made up of small particles called atoms that cannot be destroyed, created, or subdivided by physical and chemical changes.)

A **scientific law** is a description of what we find happening in nature over and over in the same way, without known exception. (Law of Gravity, the Law of Conservation of Matter states that we can change matter from one physical or chemical form to another, but no matter is created or destroyed by such processes).

Accuracy is the extent to which a measurement agrees with the accepted or correct value for that quantity.

Precision is a measure of reproducibility, or how closely a series of measurements of the same quantity agree with one another.

Controlled experiment - to test a hypothesis. Consists of two groups:

1. **experimental group**, in which the variable is changed in a known way
2. **control group**, in which the variable is not changed

A double blind experiment in which a group of patients is given a placebo, and a new drug is tested on another group. Scientists cannot prove a hypothesis to be true in all cases. They can only prove it to be false under specific conditions.

Types of reasoning

Inductive - uses observations and facts to arrive at generalizations or hypotheses.

Deductive - uses logic to arrive at a specific conclusion based on a generalization or premise. From general to specific.

Frontier Science is controversial because it has not been widely tested and accepted.

Consensus Science consists of data, theories, and laws that are widely accepted by scientists considered experts in the field involved.

Technology is the creation of new products and processes intended to improve our efficiency, chances for survival, comfort level, and quality of life.

Environmental Science is the study of how the biotic (living) environment interacts with one another and with the nonliving environment (abiotic). Where as ecology is a pure science – environmental science is an applied science using chemistry, biology, ecology geology, physics and mathematics.

Systems and System Models

System - is a set of components that function and interact in some regular and theoretically predictable manner.

A system has

- **structure** - consists of components or parts that fit together to make a whole, and
- **function** - what the system does. (e.g., circulatory system)

Models are used as approximate representations or simulations of real systems to find out which ideas or hypotheses work. Mathematical models require three steps:

1. Make a guess and write down some equations,
2. Compute the predictions implied by the equations, and
3. Compare the predictions with observations, the predictions of mental models, existing experimental data, and scientific hypotheses, laws, and theories.

Mathematical models are important because they can give us improved perceptions and predictions, especially concerning matters for which our mental models are weak.

Some Basic Components and Behaviors of System Models

Any system being studied has one or more **inputs** (such as matter, energy or information). Inputs accumulate in the environment, such as population. Inputs flow through a system at a certain rate. Such flows or throughputs of matter, energy, or information through a system are represented using arrows. Anything flowing out of a system is called an **output**.

- A **feedback loop** occurs when one change produces some other change, which reinforces or slows the original change. They occur when an output of matter, energy or information is fed back into the system as input.
- **Positive feedback loop** is a runaway cycle in which a change in a certain direction provides information that causes a system to change further in the same direction.
- **Negative feedback loop** occurs when one change leads to a lessening of that change.
- **Homeostasis** - the maintenance of favorable internal conditions despite fluctuations in external conditions. Homeostatic systems consist of one or more negative feedback loops that help maintain constant internal conditions when changes occur.

Most systems contain one or a series of coupled positive and negative feedback loops. The idea that life on earth helps sustain its own environment is a modified version of the **Gaia hypothesis**, proposed in the early 1970s by James Lovelock and Lynn Margulis.

Some Behaviors of Complex Systems

Complex systems often show **time delays** between the input of a stimulus and the response to it. A long delay can mean that the corrective action comes too late. (e.g., smoker who quits but already has lung cancer)

Synergistic reactions occur when two or more processes interact so that the combined effect is greater than the sum of their separate effects. Synergy amplifies the action of positive feedback loops and thus can amplify a change we believe is favorable. Can also bring about harmful changes.

Some systems are now appearing to be random, chaotic, and unpredictable. This behavior of systems comes from within the system itself, and is said to be generating **chaos**.