Discusses lots of interesting stuff:
- Time travel
- Virtual reality
- Multiple universes
- Free will

“I remember being told, when I was a small child, that in ancient times it was still possible for a very learned person to know everything that was known. I was also told that nowadays so much is known that it is inconceivable that anyone could learn more than a tiny fraction of it in a long lifetime. The latter proposition surprised and disappointed me. It was not that I wanted to memorize all the facts that were listed in the world’s encyclopedias and telephone directories. On the contrary, I hated memorizing facts. That is not the sense in which I expected it to be possible to know everything that was known.... I had in mind a more discriminating idea of what should count as being known. By ‘known’ I meant understood.”

David Deutsch, Winner of Paul Dirac Prize for Physics

Scientific Theory

- Predicts the behavior of a system in an infinite number of cases
- Reveals previously unsuspected behavior of a system

Assumptions of Science

- The world is real.
- We can accurately perceive the world.
- Natural processes are sufficient to understand the world.
- Natural processes operate uniformly throughout space and time (i.e., natural laws exist).

Nickels (1998)

Types of Reasoning

**Induction** - drawing a general conclusion based on a collection of specific observations.

**Deduction** - drawing inferences about a specific case on the basis of a general principle.

**The Scientific Method** is a union of inductive and deductive reasoning.

**Inductive** - Constructing models

**Deductive** - Predicting results of experiments
**A Continuum of Models**

Simple \[\rightarrow\] Highly tractable

Too specific \[\rightarrow\] Intractable

Very general \[\rightarrow\] Complex

**Example:**

- Simple: \(y = bx + c\)
- Complex: \(y = ax^2 + bx + c\)

**Relationships could be misleading!**

- Early studies reported that pipe smokers lived longer than nonsmokers.
- Pipe smokers tend to be wealthier than most people, possibly leading to longer life through better health care.

**Correlation vs. Causation**

A **correlation** is an association between variables.

Example: Smokers are more likely to get lung cancer than non-smokers.

A **causation** is a mechanistic relationship between two variables. Experiments are needed to verify causation.

**Does smoking really cause cancer?**

...two classes of alternative theories which any statistical association, observed without the predictions of a definite experiment, allows—namely, (1) that the supposed effect is really the cause...or (2) that cigarette smoking and lung cancer, though not mutually causative, are both influenced by a common cause, in this case the individual genotype.

[Source: 1957, British Medical Journal 2: 297-298]

**Sir Ronald Fisher**

(founder of modern statistics)

**Traditional Scientific Method**

1. Observe and describe a phenomenon.
2. Formulate a hypothesis to explain the phenomena (usually in the form of a mathematical relationship).
3. Use the hypothesis to predict the existence of other phenomena.
4. Perform an experimental test of the predictions.
5. Refine the hypothesis based on results of the experiments.

**Apply the Scientific Method**

1. Observe and describe a phenomenon.
   - Smokers tend suffer lung cancer more than non-smokers do.
2. Formulate a hypothesis to explain the phenomena.
   - Chemicals in cigarettes induce cancer.
3. Use of the hypothesis to predict the results of new observations.
   - Predicts that subjecting individuals to cigarette smoke would result in a higher frequency of lung cancer.
4. Perform an experimental tests of the predictions.
   - Subject individuals to cigarette smoke for some duration and examine lung tissue for evidence of tumors.
5. Refine the hypothesis based on results of the experiments, and repeat steps 3 and 4 until there are no discrepancies between theory and observation.
When does a correlation imply causation?  
Smoking and Lung Cancer

1. Strength - Is the risk so large that we can easily rule out other factors?
2. Consistency - Have the results been replicated by different researchers and under different conditions?
3. Specificity - Is the exposure associated with a very specific disease as opposed to a wide range of diseases?
4. Temporality - Did the exposure precede the disease?
5. Biological gradient - Is increasing exposure associated with increasing risk?
6. Plausibility - Is there a credible scientific mechanism that can explain the correlation?
7. Coherence - Is the correlation consistent with the natural history of the disease?
8. Experimental evidence - Does a physical intervention show results consistent with the correlation?

Hill (1965)

- There certainly is a strong association.
- The results are consistent across a wide range of researchers and studies.
- Smoking is not specific as it is associated with a wide range of diseases besides cancer.
- Smoking precedes cancer, sometimes by several decades.
- There is a dose response relationship (heavy smokers are at greater risk than light smokers).
- I'm not sure if we know enough about cancer to provide a specific mechanism. Perhaps we can invoke some of the ideas we know about how certain chemicals can cause DNA damage.
- There is coherence in that lung cancer rates rise with smoking rates and the rates are higher in countries where a lot of people smoke.
- Experimental interventions do work. Getting people to quit smoking has been shown to greatly reduce their risk for cancer.

Steve Simon, Children's Mercy Hospital
Apply the Scientific Method

1. Observe and describe a phenomenon.
   Car does not start.

2. Formulate a hypothesis to explain the phenomena.
   Battery is not charged.

3. Use of the hypothesis to predict the results of new observations.
   Predicts that replacing the battery with a newly charged battery will enable one to start the car.

4. Perform an experimental tests of the predictions.
   Either charge the current battery or put in a new battery and try to start the car.

5. Refine the hypothesis based on results of the experiments, and repeat steps 3 and 4 until there are no discrepancies between theory and observation.

Affirming the Consequent: A Logical Fallacy

• If A then B.
  But if B, not necessarily A.

• Example:
  If creation is true, then evolution is false.
  But if evolution is false, not necessarily creation is true.

Alternative explanations for the diversity of life include countless creation myths.

Babylonian, Olori, Korean, Japanese, Navejo, Norse, Indian, Comanche, Chinese, Chelan, Pima, Mayan, Miwok, Scandinavian, Salish, Australian Aboriginal, Hopi, Tahitian, Yokut, Egyptian, Mande, Yoruba, Micmac, Lakota, Romanian, Mongol, Assyrian, Maori, 
Christian & Jewish, Aztec, Diqueno, Apache, African, Dakota, Hungarian, Iroquois, Inuit, Huron, and Hawaiian.

Strong Inference

1. Devise alternative hypotheses.
2. Devise a crucial experiment.
3. Carry out the experiment so as to get a clean result.
4. Recycle the procedure, making sequential hypotheses to refine the possibilities that remain.

Platt (1964), Science, 146: 347-353
Using Strong Inference

1. Observe and describe a phenomenon.
   Car does not start.

2. Formulate multiple hypotheses to explain the phenomena.
   Battery
   Alternator
   Starter
   Spark plugs

3. Use of the hypothesis to predict the results of new observations.
   Predict observable signs of the failure of each part

4. Perform an experimental tests of the predictions.
   Perform experiment to distinguish between hypotheses.

5. Refine the hypothesis based on results of the experiments.

Limitations of Strong Inference

- More than one hypothesis might be correct at the same time.

- In practice, the simplest explanation that covers the facts is considered the most plausible.