November 2, 2005
The History & Logic of Science
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A. History of Science: Ancient Greece (Thales, approx. 635-543 BCE)

- What we understand to be Western science emerged from the work of the pre-Socratic *philosophers of nature*, beginning with Thales.
- These pre-Socratics established the domain of science as the natural world (all that exists physically and naturally, both on earth and in the heavens; i.e., not the supernatural world).
- The pursuit of science seeks to explain what happens in the natural world:
    - *Explanandum* = that which requires explanation.
- Unlike mythology (which explained natural events by referring to the gods), natural philosophers sought to explain events in the natural world by appealing to other features of the natural world:
    - *Explanans* = that which does the explaining.
- So, science attempts to explain the natural world by reference to the natural world.

- Everyday observation revealed that some events occur regularly. What explains this regularity?
- These explanations typically took on the form of formulating general laws which were said to govern a variety of natural events: general laws explained by we observed regularities in nature.
- Unlike mythological explanations (which offered personal, particular explanations of events: *this* flood occurred for *this* reason), general laws explained a whole range of discrete natural events.
- Thanks to the influence of such natural philosophers as Pythagoras, these general laws were typically expressed in mathematical language.
- So, these general laws are hypothesized to explain regularities observed in the natural world; while these general laws are not themselves directly observed, their effects are observed.
- Explanations based on such generalizations are not just reports of *what* happens, but *why* such events occur.

- Science in Ancient Greece was not publicly funded; instead, individual natural philosophers worked in privately-funded schools of scholars.
- This individualistic character shaped the idea that naturalistic explanations were actively defended in the shape of a rational debate: actively supporting their ideas by giving reasons, citing observations, and offering proofs (again, influenced by the proofs found within mathematics).
- Importantly, in the case of Parmenides and Zeno, this rational debate included theorizing that questioned the veracity of sense perception.
- To this extent, early Greek science offered logical arguments and rational proofs aimed at uncovering the fundamental structure of the natural world (identifying the basic elements of the world, the basic forces that shaped that world, etc.).

- The lack of institutional affiliation and public funding freed the early Greeks from intellectual inquires that demanded practical application: they were free to pursue theoretical knowledge of nature.
- This is often referred to as "knowledge for the sake of knowledge".
- In any event, this sort of social organization was unique to the Greeks, and hence what the Greeks were able to generate was also unique to the Greeks: the pursuit of self-consciously theoretical investigations into the natural world.

Domain:	The natural world is to be explained by reference to the natural world.
	General "laws of nature" explain a wide variety of natural events.
Methodology:	Careful, systematic observations.
	Formulation of universal laws to explain observed regularities.
	Rational argumentation for support.
Aim:	Theoretical knowledge of nature (knowledge for the sake of knowledge).

B. History of Science: The Scientific Revolution (approx. 1543-1700)

As an episode in human history, the Scientific Revolution is one of the most studied.
It is a complex series of events that includes

- transformations in science (especially astronomy and physics),
- conflicts between science and religion,
- rejection of ideology,
- incorporation of experimentation and instrumentation,
- as well as a change in the social status of science (as a state-funding, practical inquiry).

- Complex episode in human history: roughly from Copernicus to Newton.
- Transformation of the physical sciences:
  - In astronomy: from geocentrism to the heliocentrism.
  - In physics: from Aristotle's view of motion to the New Mechanical Philosophy of Descartes & Newton.
- Incorporation of new methodologies: Experimentation and Instrumentation (esp. with Galileo, Boyle).
- Scientific explanations still in the form of general laws (extremely mathematical in character).
- Bacon's emphasis on The Inductive Method (hypotheses are "induced" from observations), and the overall social utility of science ("knowledge is power").

C. Logic of Science: Induction & Confirmation

- Induction: from particular observations we infer general statements.
  - Particular Observation: This object S has property P.
  - General Statement: All objects of type S have property of P.

O_1: S_1 is P.
O_2: S_2 is P.
… …
O_n: S_n is P.
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Probably: All S are P.

- Important note: unless we observe all such objects, the truth of the general statement is probabilistic.
- Next, when we observe S_{n+1} and discover that it, too, has property P, that observation is said to "confirm" (or provide evidence for) the general statement (thus making it more probable).
- It is rational to believe general statements that are confirmed by observation.
- So, observation (gathering data) is crucial for generating, testing, and justifying scientific hypotheses.
  - Problem 1: Do scientists really generate, test, and justify hypotheses in this way?
  - Problem 2: Can we really test hypotheses in this way?
  - Problem 3: Can we ever really "confirm" or "justify" a hypothesis in this way?
- This leads to the general worry known as "underdetermination":
  - general hypotheses will always "out pace" the evidence; thus, for the same set of empirical data, there will always be more than one rival hypothesis that is equally well-supported.
  - So, no matter how much evidence is gathered, a theory is never exclusively supported.
  - Thus, in order to choose between competing theories, we must invoke criteria other than empirical adequacy:
    - including: simplicity, explanatory breadth, fruitfulness, consilience, etc.

D. Logic of Science: Deduction & Falsification

- Karl Popper proposes an entirely new approach to science: Conjecture & Refutation.
    - First, we offer a conjecture: a bold, creative hypothesis or theory about the world (the bolder the better).
    - Next, we attempt to refute/falsify this hypothesis by exposing it to rigorous empirical testing.

- While a hypothesis cannot be inductively confirmed, it can be deductively falsified with a single observation.
- Does not provide certainty (nor even any sense of increasing probability) for scientific theories; rather, all Popper can say is that a conjecture, theory, or hypothesis *has not yet been refuted*.
- Testing is a purely "subtractive" process; there is no "logic of discovery" because it relies on creative insight.
- Thus, we must maintain a *tentative attitude* toward all of our as-yet-unfalsified theories.
  - Problem 1: Realistically, do we really hold views with such tentativeness? In medicine? In engineering? Or does our confidence tend to increase as a theory survives testing? *Should* our confidence increase?
  - Problem 2: As a theory survives on-going testing, it never becomes more probable; in fact, a "tried-and-tested" theory is no more rationally preferable to a "new-and-barely-tested" theory, so long as neither has yet been falsified. Doesn't that seem a bit odd?
  - Problem 3: There is no rational guide for theory generation; nor is there any guide for theory modification; every theory (so long as it is falsifiable in principle) is a legitimate concern for scientific testing.
- Yet another significant problem awaits Popper, known as "holism in testing":
  - This problem suggests that when we try to "falsify" a scientific theory/hypothesis, it is impossible to adequately "isolate" the theory/hypothesis in question.
  - What we've actually falsified is a whole constellation of theories, background assumptions, auxiliary hypotheses, etc.
  - All that we can conclude is that some part of this collection of theories and assumptions is mistaken.
  - Thus, according to this problem, contradictory empirical evidence does not falsify a single theory; in the face of seemingly contradictory evidence, we can always "save our theory" by rejecting something else.

<u>E. Logic of Science: Kuhn & Paradigms</u>

- Historian and Philosopher of science Thomas Kuhn suggests a revolutionary approach to science.
- Science exhibits a pattern of Normal Science punctuated by periods of Revolutionary Science.
  - <u>Normal Science</u>: scientists work within a common "paradigm" or "framework" that includes a blueprint of the various puzzles to solve and the ways to solve them; occasionally, some puzzles resist solution, and they become problems; when problems persist, they are called anomalies; when anomalies build up, the scientific paradigm is in crisis.
  - <u>Revolutionary Science</u>: a new paradigm emerges that is able to solve these anomalies, but includes vastly different fundamental assumptions about the world (how it is organized, what exists, what forces operate, etc.); eventually, this new paradigm wins out, and Normal Science resumes.
- This challenges the common view that scientific change is continuous and cumulative (i.e., progressive).
- Moreover, Kuhn maintained that a paradigm sets the standard for what counts as a "good" explanation; and because different paradigms will have different standards, this leads to the notion of "incommensurability":
  - Because each paradigm comes with its own set of methods and standards, there is no rational (fair) way to choose between paradigms (except by merely presuming the standards of your own paradigm).
  - Thus, there is no "common measure" by which to rationally assess a scientific paradigm (including its various sub-theories, etc.); the only measure is "internal coherence".
- Some people understood Kuhn to be saying that science is irrational or relativistic.
- However, Kuhn resisted this conclusion: he thought that you *could* make rational progress in science:
  - Some paradigms replaced other paradigms by subsuming them (solving all the same puzzles as the old paradigm, as well as solving the anomalies); so we can rationally choose those paradigms that are better at solving problems; it's much more difficult, however, when two paradigms are significantly different!
  - The choice between paradigms is not one of relativism, but of pluralism and/or contextualism: there is still a "real world" out there beyond our paradigm; however, there may well be more than one "good" or "rational" way to understand that world; so, it's not "anything goes"! (That's the next Philosopher: Feyerabend!)