Science Wars: What Scientists Know and How They Know It

Part I

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Steven Goldman has degrees in physics (B.Sc., Polytechnic University of New York) and philosophy (M.A., Ph.D., Boston University) and, since 1977, has been the Andrew W. Mellon Distinguished Professor in the Humanities at Lehigh University. He has a joint appointment in the departments of philosophy and history because his teaching and research focus on the history, philosophy, and social relations of modern science and technology. Professor Goldman came to Lehigh from the philosophy department at the State College campus of Pennsylvania State University, where he was a co-founder of one of the first U.S. academic programs in science, technology, and society (STS) studies. For 11 years (1977–1988), he served as director of Lehigh's STS program and was a co-founder of the National Association of Science, Technology and Society Studies. Professor Goldman has received the Lindback Distinguished Teaching Award from Lehigh University and a Book-of-the-Year Award for a book he co-authored (another book was a finalist and translated into 10 languages). He has been a national lecturer for Sigma Xi—the scientific research society—and a national program consultant for the National Endowment for the Humanities. He has served as a board member or as editor/advisory editor for a number of professional organizations and journals and was a co-founder of Lehigh University Press and, for many years, co-editor of its Research in Technology Studies series.

Since the early 1960s, Professor Goldman has studied the historical development of the conceptual framework of modern science in relation to its Western cultural context, tracing its emergence from medieval and Renaissance approaches to the study of nature through its transformation in the 20th century. He has published numerous scholarly articles on his social-historical approach to medieval and Renaissance nature philosophy and to modern science from the 17th to the 20th centuries and has lectured on these subjects at conferences and universities across the United States, in Europe, and in Asia. In the late 1970s, the professor began a similar social-historical study of technology and technological innovation since the Industrial Revolution. In the 1980s, he published a series of articles on innovation as a socially driven process and on the role played in that process by the knowledge created by scientists and engineers. These articles led to participation in science and technology policy initiatives of the federal government, which in turn led to extensive research and numerous article and book publications through the 1990s on emerging synergies that were transforming relationships among knowledge, innovation, and global commerce.

Professor Goldman is the author of The Teaching Company course *Science in the Twentieth Century: A Social Intellectual Survey* (2004).

Table of Contents

Science Wars: What Scientists Know and How They Know It

Part I

The 17th Century

The 18th Century

The 19th Century

Science Wars:
What Scientists Know and How They Know It

Scope:

The objective of this course is to explore, in depth, the nature of scientific knowledge and of the claims to truth that scientists make on behalf of their theories. Are scientific theories true because they correspond to reality? How can we know that they do, given that we have no access to reality except through experience, which scientists themselves tell us is profoundly different from the way things "really" are? Are theories true because they account for experience and make correct predictions? This sounds plausible, but theories that we now consider wrong once were considered true because they accounted for our experience and made successful predictions then! Should we assume that as new experiences accumulate, current theories will be replaced, as all previous theories have been? But in that case, theories are not really knowledge or truth, in the strict sense of those words, but a special case of experience-validated educated opinion.

These are more than just intellectually interesting questions. The roles that science has come to play in contemporary society and world affairs make the answers to these questions important to society, particularly to the citizens of democratic societies who have an opportunity and an obligation to influence science policy decisions. Furthermore, since the 1960s, science has come under broad political, intellectual, and religious attack—erupting in the 1980s in what was called the "Science Wars"—even as it achieved unprecedented recognition and support as both critical to social well-being and the crown jewel of Western cultural achievement.

The first lecture in this course describes the post-1960 attacks on science and relates them to conflicting conceptions of knowledge, truth, and reality in the history of modern science and, more broadly, in the history of Western philosophy.

Lectures Two through Five are devoted to the 17th century and the conflicting conceptions of scientific knowledge promoted by the "founding fathers" of modern science: Francis Bacon, René Descartes, and Galileo Galilei. It quickly becomes clear that there was then, and is now, no such thing as "the" scientific method, no one method that can transform naive empirical experience into knowledge of nature.

Lectures Six, Seven, and Eight are devoted to 18th-century responses by nonscientists to the growing acceptance of Newtonian science as the truth about reality, climaxing in the Enlightenment proclamation of an Age of Reason with science as its living model. The central figures in these three lectures are John Locke, Bishop George Berkeley, David Hume, and Immanuel Kant.

It was in the 19th century that modern science truly came of age, with the formulation of theories in physics, chemistry, and biology that were far more sophisticated, abstract, powerful, and useful than 17th- and 18th-century theories. But for those very reasons, these theories made more pertinent than before questions about the nature, scope, and object of scientific knowledge. What were these theories about, given that the reality they described was so different from human experience; given, too, the need for increasingly complex instruments to access this reality and the increasingly esoteric professional languages in which scientific descriptions of the world were formulated? Lectures Nine through Twelve are devoted to the range of interpretations among leading scientists of what *knowledge* and *truth* mean in science, and of how they are arrived at using some combination of instruments, experiments, ideas, facts, and logic.

If the maturation of modern science was a 19th-century phenomenon, the maturation of philosophy of science, that is, of the systematic study of scientific reasoning and scientific theories as products of that reasoning, is a 20th-century phenomenon. Lectures Thirteen through Twenty-Two are devoted to exploring the rich and innovative responses to science as knowledge by scientists, philosophers, historians, and sociologists from 1900 through the early 21st century. Lecture Thirteen surveys the state of theories of science at the turn of the century, the social status of science, and its cultural impact, especially on religion and art. Lecture Fourteen traces the interpretation of science as deductive knowledge, focusing on the highly influential movement known as Logical Positivism.

The evolution of quantum theory, from Planck's initial tentative hypothesis through the formulation of quantum mechanics in the mid-1920s, raised new questions about the relationship of science to reality, as well as about the ability sharply to distinguish objectivity and subjectivity. Lecture Fifteen addresses these questions, which continue unresolved to this day. Concurrently, a number of thinkers inside and outside of science began reassessing the claim of science to possess universal, objective truths about nature. Lectures Sixteen through Eighteen explore this reassessment, moving from interpretations in the 1930s of social influences on what we accept as knowledge to historicists' interpretations of scientific knowledge just before and after 1960.

Lectures Nineteen through Twenty-Two explore the increasingly aggressive critiques of scientific knowledge from the 1970s through the 1980s, climaxing in the Science Wars of the 1990s. They describe both the postmodernist attack on science and new attempts to defend science as a privileged form of knowledge and truth.

Lectures Twenty-Three and Twenty-Four address the creationism-intelligent design versus evolution controversy in light of contemporary interpretations of science and the implications of these interpretations for science policy and rational action as we enter the 21st century.

Lecture One

Knowledge and Truth Are Age-Old Problems

Scope: Modern science began as a method for solving one form of the problem of knowledge, knowledge of nature, but soon promoted itself as the only rational response to experience, alone capable of knowledge of the true causes of experience. This "imperialism" pitted science against all other claimants to knowledge, truth, and rationality, triggering the Science Wars that marked the late 20th century. These wars arrayed humanist intellectuals and many social scientists against natural scientists over the very possibility of objective knowledge. Concurrently, science and religion clashed over the truth of evolutionary theory, and bitter political disputes erupted over the role science could or should play in public policy decisions. Differentiating knowledge from opinions and beliefs is a problem that was well known to classical Greek philosophers and has played a contentious role in Western cultural history. *Is* there such a thing as knowledge, and if there is, who possesses it, how do they get it, and what power does it give them?

Outline

I. What is it that scientists know, and how do they know what they know?

- **A.** In the 1950s, the natural sciences had, after 350 years, arrived at the very center of social power and influence.
  - **1.** Natural scientists conceived of science as having a monopoly on knowledge, truth, and reason, a monopoly on disclosing reality.
  - **2.** The justification for this claim was the explanatory and predictive power of scientific theories and the increasing control over nature these theories have given us through their association with technological innovation.
  - **3.** Concurrently, science became entrenched in commercial, governmental, and educational institutions, leading to a broad public identification of scientific research with social and economic progress.
- **B.** The relationship between science and society had changed dramatically in the 20th century, and by the 1960s, science was riding higher socially, politically, and culturally than ever before in its history.
  - **1.** By making technological innovation the basis of profitability, industry became increasingly dependent on science-based engineering, as well as on research scientists.
  - **2.** The dependence of industry on science and technology transformed postsecondary education at a time when social changes drove an unprecedented demand for postsecondary education.
  - **3.** Governments became increasingly dependent on science-related technologies for military applications, and science advice became more and more central to potentially divisive public policy issues, from Sputnik and nuclear power to global warming and stem cell research.
- **C.** At the peak of its social, political, and economic power, natural science came under attack on a broad front.
  - **1.** In the 1960s, (natural) science came under attack as a "tool" of political, militarist, and corporate interests whose funding made scientific research subservient to parochial institutional agendas.
  - **2.** Concurrently, an intellectual critique, which resulted in the proclamation of "Science Wars," was launched that challenged the objectivity of scientific knowledge and the claim that scientific knowledge was value-neutral and validated by correspondence with reality.
  - **3.** Quite independently of this intellectual critique, science was attacked by a resurgent religious fundamentalism that rejected the uniqueness of scientific truth claims.

II. The post-1960 Science Wars were an expression of a conflict internal to modern science that is itself best understood as a deep conflict within Western philosophy.

- **A.** We must understand what scientists mean when they use the word *know* before we can assess the truth of scientific knowledge claims and their implications for society.
  - **1.** Western philosophy essentially begins with a "war" over the definition of *reason*, over the claim that there is such a thing as knowledge, which is superior to belief and opinion because it is certain and universal.

    2. Plato and Aristotle defended the existence of such knowledge against the Sophists: relativists and skeptics who argued that there were only more or less probable beliefs and opinions, but no knowledge.
    3. The battle over the definition of *reason* in Plato's dialogue *The Sophist* is, thus, the original Science War.
  - **B.** But even today, there is no consensus on how knowledge in the strict philosophical sense is possible.
    1. Long before Plato, Greek thinkers had made mathematics the exemplar of knowledge.
    2. They made deductive reasoning, the form of reasoning used in mathematics, the form of reasoning linking thought and reality.
    3. What emerged from all this was a definition of knowledge as that about which we could not be wrong, thus that which was certain, necessary, and universal, just like the theorems of Euclidean geometry, and a "revelation" of reality. Thus, what scientists know is what is real and true.
  - **C.** And what if knowledge is not possible? What about the arguments of the Sophists, relativists, and skeptics?
    1. The opponents of the Platonic-Aristotelian view argued that human reasoners were limited to beliefs and opinions.
    2. Beliefs and opinions are inevitably uncertain, more or less probable, and context dependent, or particular.
    3. The founders of modern science were well aware of these knowledge "battles," and modern science is intrinsically ambivalent about the reality of scientific knowledge, making the Science Wars inevitable.

- **III.** How do we propose to explore the Science Wars?
  - **A.** The approach adopted here is historical, with the objective of allowing an informed assessment of the status of scientific claims to knowledge and truth. Why use a historical approach, rather than a contemporary analytical one?
    1. A historical approach allows us to "watch" the problem of knowledge changing over time, correlative with developments in science and in philosophy and with the changing science-society relationship.
    2. It also reveals that conflict among competing conceptions of the problem of knowledge and proposed solutions to it is an ongoing process internal to science.
  - **B.** The perception that knowledge poses a problem for science truly does have a history: There is more here than merely telling a story in time.
    1. From the generation of Descartes and Galileo until the end of the 19th century, we will see that it was primarily scientists who responded to this problem as a problem for science.
    2. In the 20th century, by contrast, we will see that responsibility for solving the problem posed by scientific knowledge shifted to philosophers.
    3. We will "watch" as philosophy, history, and sociology of science emerge as subspecialties devoted to clarifying and solving this problem, with scientists decisively out of the loop on their own problem!
  - **C.** The historical approach involves many people and many ideas, but the lectures focus on recurring issues and themes.
    1. First, we will look at the "grand" conflict between universal, necessary, and certain, as opposed to particular, contingent, and probable, conceptions of knowledge, truth, reason, and reality.
    2. Second, we will see that this conflict is internal to science, is the ultimate source of all forms of the post-1960s Science Wars, and has direct implications for the role science can play in public policy debates.
    3. Third, that conflict fits within a broader conflict over the nature of rationality and truth that has played an important role in Western culture since the time of the ancient Greeks.
    4. Finally, the endurance of this conflict strongly suggests that it is fundamental to the human condition and cannot be solved by dismissing one side or the other: We must live with both!

Recommended Reading:

Richard Popkin, *A History of Skepticism from Erasmus to Descartes.*

Thomas Kuhn, *The Copernican Revolution.*

Questions to Consider:

1. Why has the philosophical conception of knowledge had such a hold on Western thinkers? John Dewey thought that this was religion continued under another name. Why?
2. Before assimilating the material in these lectures, jot down the role you think scientific knowledge *ought* to play in relevant public policy and public education issues.

Lecture Two

Competing Visions of the Scientific Method

Scope: Studying natural phenomena in a systematic way, and seeing in them the lawfully produced visible effects of invisible causes, long predates the 17th-century Scientific Revolution. A mathematical-experimental approach to the study of nature first emerged in the 13th century in Western Europe and was applied aggressively in the 16th century; thus, the rise of modern science did not occur in a cultural vacuum. By the early 17th century, technological and conceptual innovation in the West was already displaying exponential growth. Works by two thinkers, Francis Bacon and René Descartes, on the possibility of knowledge of nature and on how to get it were perceived at the time and after as heralding the birth of "modern" science. They also herald what would be the enduring problem of scientific knowledge. Bacon championed an experiment-intensive, inductive approach to knowledge of nature that minimized both mathematics and an active role for mind. Descartes championed a mathematics-intensive, deductive approach that assigned a central role to mind and only a marginal role to experiment. This should cast doubt on the popular notion that the rise of modern science was the result of discovering "a" method for extracting objective truths about nature from subjective experience.

Outline

I. Modern science did not rise newborn in the early 17th century. It represented an innovative form of natural philosophy indebted to medieval and Renaissance antecedents.

- **A.** There are four "legacy" ideas on which modern science rests.
  - **1.** The task of natural philosophy is to explain natural phenomena in terms of causes.
  - **2.** In explaining natural phenomena, nature must be treated as a closed system epistemologically (natural phenomena can be explained as the effects of natural causal agents only). This rule is first found in the 12th-century treatise *Natural Questions* by the English monk Adelard of Bath. In the 13th century, this was extended to include nature as closed ontologically (after the creation, nothing fundamental can be added to nature or destroyed).
  - **3.** Knowledge of nature must be based on direct experience or repeatable experiments, not textual statements by authorities.
  - **4.** Mathematics is a "language" for describing natural phenomena.
- **B.** Natural philosophy during the Renaissance was the seedbed of modern science and 1543 in particular was a "miracle year" for the study of nature in the Renaissance in terms of influential books published.
  - **1.** Copernicus's *On the Revolution of the Heavenly Spheres* laid the foundation for modern astronomy, dismissing Ptolemaic and Aristotelian astronomy.
  - **2.** Vesalius's *On the Structure of the Human Body* laid the foundation for modern anatomy and medical science, overthrowing the established teachings of the ancient Roman physician Galen of Pergamon.
  - **3.** The publication in Latin of three texts by the Greek mathematician Archimedes influenced the rise of modern mathematical physics, especially as Galileo approached it.
- **C.** At the turn of the 17th century, the study of nature was already displaying characteristics of "modern" science.
  - **1.** This is reflected in Francis Bacon's inductive approach to knowledge of nature.
  - **2.** It is also reflected in Descartes' contrasting deductive approach to the same end.

II. The British jurist and educational reformer Francis Bacon has been recognized as the father of the experimental method in the study of nature and is one of the fathers of modern science.

- **A.** Bacon's seminal contribution to science was a purely methodological treatise, *The New Organon* (1620), that is, a work containing no new knowledge of nature but describing a method for getting such knowledge.
  - **1.** Bacon argued that the key to knowledge of nature was not genius or inspiration or mystical connection with God's mind but a "mechanical" method that revealed laws of nature in empirical data.

- **2.** Startlingly, Bacon claimed that the human mind was an obstacle to knowledge of nature—the problem, not the solution!
- **3.** Bacon identified four "idols of the mind"—idols of the tribe, idols of the cave, idols of the theater, and idols of the marketplace—four ways in which the mind is led by inherent traits and social influences to impose its speculations and fantasies onto nature, and a generic "idolatry" of the mind, as the obstacles to be overcome by his method.

B. Strictly controlled induction, Bacon argued, was the solution to the problem of acquiring knowledge of nature.

- **1.** The first step in the process that ends with knowledge of nature is collecting data, collecting all relevant data, without any presuppositions.
- **2.** The next step is analyzing the data to uncover suggestive correlations among them.
- **3.** Then comes the extended process of experimentation to test possible correlations, the formation of hypotheses, further testing, and upon confirmation, knowledge of nature's laws.

C. Was Bacon right? Can an impersonal, mechanical method generate universal, objective knowledge out of particular, personal experiences?

- **1.** Bacon's "pure," that is, presupposition-less, Empiricism, in fact, presupposes that reasoning about nature begins with uninterpreted "input" data that are simply given to the mind in experience, and it also presupposes the availability of objective relevance criteria.
- **2.** If the mind is truly passive in reasoning, how can the gap between induction and deduction be closed? In fact, no scientist has ever been a strict Baconian, although lots of scientists have claimed to be Baconian.
- **3.** Bacon himself was not a scientist and his intuitions about science were not very good. A case in point is William Harvey's experimental "proof" of the circulation of the blood, which Bacon rejected!

III. Independently of Bacon, the French mathematician and natural philosopher René Descartes proposed a deductive-rational, as opposed to Bacon's inductive-empirical, approach to acquiring knowledge of nature.

A. Ten years after Bacon published *The New Organon*, Descartes published three short works describing and applying the "correct" method for generating knowledge of nature.

- **1.** The descriptive works were his *Discourse on Method* and *Rules for the Direction of the Mind*, which argued for deductive reasoning as the only way to achieve universal, necessary, and certain knowledge of nature.
- **2.** The companion treatise on optics showed the power and fertility of using mathematics to describe natural phenomena.

B. The contrast between Cartesian Rationalism and Baconian Empiricism is clear.

- **1.** For Descartes, the mind is the solution, not the problem, as it was for Bacon.
- **2.** Truth, including true knowledge about the world "out there," is in the mind, and only *deductive* reasoning can generate that knowledge.
- **3.** Mathematics, for Descartes, is the key to scientific knowledge, while experiment is a tool of limited value, to be used cautiously because its results are equivocal.

C. Was Descartes right? That is, can logically fertile hypotheses and the mind's inner "eye" give us knowledge of that which is outside the mind? How would we know we were right?

IV. The founders of modern science, searching for universal truths of nature, were well aware of a problem with using experiments to validate universal knowledge claims.

A. Aristotle's logical writings identify Affirming the Consequent (called by some Affirming the Antecedent!) as an invalid form of deductive inference.

B. The experimental method in fact employs just this form of inference.

- **1.** It follows that the truth of what is claimed to be a universal theory, a universal law of nature, cannot be deductively certain.
- **2.** Scientific theories may be presented deductively, but they incorporate a deductive logical "flaw."

Recommended Reading:

Perez Zagorin, *Francis Bacon*.

Antonio Damasio, *Descartes' Error*.

Questions to Consider:

1. When attempting to understand a new natural or social phenomenon, how can we know in advance what information is relevant or irrelevant?
2. The mind is *not* a blank slate at birth, but are we born with innate ideas or with particular, fixed ways that the mind responds to experience? Does this make the mind part of the problem or part of the solution?

Lecture Three

Galileo, the Catholic Church, and Truth

Scope: What did Galileo actually *know* about nature? Did he, for example, *know* that the Earth moved on its axis and around the Sun? Did his telescope give him that knowledge? Did his immensely influential *Dialogue Concerning the Two Chief World Systems* prove that Copernicus was right? Did Galileo *know*, as he claimed he did, that four moons orbited Jupiter, that sunspots were on or near the surface of the Sun, that the Moon's surface was uneven, that the tides were caused by the Earth's rotation? The Catholic Church typically has been cast by historians as a villain in the condemnation of Galileo, but a great deal hinges on whether Galileo possessed knowledge and was defending truth or was promoting personal opinions based on his beliefs. Galileo employed a method of reasoning that was different both from Bacon's and Descartes' and was more influential than either. He was arguably the first modern mathematical physicist, deeply committed to the idea of nature as being intrinsically mathematical. He employed a rigorously objective and empirical method of reasoning that used experiment selectively to confirm the validity of idealized mathematical models of natural phenomena. He used thought experiments to reach scientific conclusions and, on occasion, extended the logical consequences of his idealized reasoning to nature as if he had actually observed experimentally what could not have been observed.

Outline

I. Galileo did not doubt that we can have universal, necessary, and certain knowledge, for example, in mathematics and in mathematical physics.

- **A.** Galileo's method for generating knowledge of nature is based on Archimedes's style of mathematical physics. Three treatises by Archimedes were published in Latin translations in 1543 and widely studied in Italy, stimulating an active school of Italian mathematics and mathematical physics in the last third of the century when Galileo was a student.
  - **1.** Archimedes applied mathematics to material phenomena, such as water pressure and the design of machines, in addition to optics and astronomy.
  - **2.** Galileo extended this to matter in motion generally, stating that mathematics is the very language of the "book of nature" and that mathematical forms are the "alphabet" of this language.
  - **3.** Demonstration, a name for deductive reasoning in the manner of Euclidean geometry, when applied to natural phenomena, gives us certain knowledge of nature. This knowledge is identical with God's knowledge qualitatively, but of course, not quantitatively.
- **B.** The key to Galileo's method is idealization from the concrete physical phenomenon being studied, which presumes knowing *what* in an experimental situation is essential and what is not.
  - **1.** Galileo made use of thought experiments and sometimes preferred these to actual experiments, whose results could be misleading.
  - **2.** His study of falling bodies and pendulum motion illustrate his approach to idealized mathematical modeling of natural phenomena.
  - **3.** They also illustrate his equivocal attitude to experiment and his sometimes uncritical extension of conceptual analysis to nature.

II. Galileo is, of course, best known outside science as the champion of Copernicus's astronomical theory based on his pioneering application of the telescope.

- **A.** It was Galileo's conception of knowledge that put Galileo in direct conflict with the Catholic Church.
  - **1.** In his *Dialogue Concerning the Two Great World Systems*, Galileo states that qualitatively (though not quantitatively), knowledge is the same for us and for God.
  - **2.** It was only for his insistence that Copernicus's theory was physically true, and that any reasonable person would conclude that it was true, that Galileo was called to account.
  - **3.** Had Galileo claimed that Copernicus's theory was the most effective means of making astronomical calculations, ignoring the question of physical reality, there would have been no conflict at all!

- **B.** Galileo's argument in the *Dialogue* is rhetorical/persuasive, selectively omitting information well known to Galileo and leading the reader.
  - **1.** Galileo's realist truth claim conflicted with Church teaching at a time when the Church was waging a brutal war challenging its authority as a source of truth.
  - **2.** What does Copernicus's theory require us to believe if we accept it as physically true (which Copernicus himself thought was the case)? What evidence is there that the theory is correct?

III. Galileo's *Dialogue* ignored a third "world system", that of Tycho Brahe, which was the most widely supported astronomical theory in the early 17th century. Why Galileo ignored it is very revealing.

- **A.** Can seeing by itself, uninterpreted seeing, be knowing?
  - **1.** Brahe's theory and Copernicus's theory are indistinguishable empirically, given the instruments available to Galileo.
  - **2.** More generally, Galileo's telescope was incapable of proving either that the Earth rotated on its axis or that it revolved around the Sun.
  - **3.** The telescope revealed that Venus had phases, which may be said to prove that it orbits the Sun, but Brahe's theory predicted that, too.
- **B.** Galileo emerges as a polemicist for the Copernican world view.
  - **1.** Galileo ignored Brahe because he did not believe Brahe's theory was correct.
  - **2.** Including Brahe's theory, which is just as well supported by the telescope as Copernicus's, would have undermined the contrast between Copernicus's theory and the clearly false Ptolemaic theory as the only options for a true theory of the heavens.
  - **3.** Galileo also ignored his fellow Copernican advocate Kepler's arguments that the planets move at non-uniform speeds and in elliptical, not circular, orbits.
- **C.** Galileo's physics clearly reveals both that experience/experiment-based science of nature requires that we accept conclusions that contradict experience and that scientific reasoning is complex.
  - **1.** Studying Galileo's work in light of the subsequent history of physics reveals the inevitability of assumptions in scientific reasoning.
  - **2.** One of Galileo's assumptions was that circular motion was natural. (A decade after Galileo died, the Dutch mathematician-physicist Christian Huyghens successfully demonstrated that circular motion is forced motion, thereby altering the course of mathematical physics).
  - **3.** Did Galileo discover facts, as an archaeologist discovers buried artifacts, uncovering them, or did he *construe* experience in ways that "made" new facts?

Recommended Reading:

William R. Shea, *Galileo in Rome: A Troublesome Genius*.

Galileo Galilei, *Dialogue Concerning the Two Chief World Systems.*

Questions to Consider:

1. Given Galileo's self-identification as a son of the Catholic Church, was he right in promoting a theory of astronomy that the Church officially denied, or was the Church right in punishing him for promoting that theory?
2. Would you have been a Copernican in 1630? Why or why not?

Lecture Four

Isaac Newton's Theory of the Universe

Scope: For more than 200 years, Isaac Newton epitomized the genius of modern science. Newton's universal theory of gravity, with its proof of the Kepler-Copernicus hypothesis and explanation of the Earth's tides; his comprehensive mathematical theory of matter in motion; particle theory of light; invention of the calculus and reflecting telescope; among many other achievements, made Newton, and reason as employed by Newton, exemplars of the possibility of knowledge of reality. His approach to reasoning about nature dominated physical science for 200 years. He employed a method that was putatively Baconian and anti-Cartesian but, in fact, was neither and owed a great deal to Galileo. Newton's physics, however, was based on very different assumptions from Galileo's, and the very success of Newtonianism, inside and outside of physics, raises again the question of whether scientists *discove*r truths about nature, in the manner of archaeologists uncovering buried ruins and artifacts, or *construct* interpretations of experience that are judged according to standards of effectiveness formulated by scientists themselves. Insight into what Newton felt that he knew of reality, and what he believed about reality, is revealed in a series of letters exchanged between one of his followers and the great German philosopher-mathematician Gottfried Wilhelm Leibniz.

Outline

I. Newton's multifaceted genius—the bulk of the almost 5 million words of manuscript he left as his legacy deal with theology, biblical interpretation, ancient history, world chronology, and alchemy; the rest with physics, mathematics, and chemistry—lay not in unique powers of deductive reasoning but in the creativity he brought to his reasoning.

- **A.** Newton's *Mathematical Principles of Natural Philosophy* (1687 in the original Latin edition) defined the conceptual framework of mathematical physics for 250 years. It contained a new, definitive mathematical theory of matter in motion, a theory of universal gravitation and of our Solar System, and a methodology for modern science.
  - **1.** None of Newton's three laws of motion, which were soon universally adopted as laws of nature, could be deduced from experiment. They were explanatorily fertile presuppositions, creatively projected onto nature as principles of nature.
  - **2.** They were, of course, consistent with experience, and they successfully predicted the behaviors of material objects moving under a wide range of forces, which encouraged their acceptance as truths of nature.
  - **3.** The law of inertia, for example, never was, nor ever could be, confirmed experimentally. It stipulates as a universal law what early modern nature philosophers believed: that matter was inanimate, that is, that matter could not move itself.
  - **4.** The third law, that for every action on a material object there must be an equal and opposite reaction, also is effectively stipulative.
- **B.** In effect, the conceptual elements of Newtonian mechanics are Newton's recognition of what must be accepted as true *in order to have* a mathematical theory of matter in motion.
  - **1.** Newton needed to define space and time, matter, motion, and force in ways that would make relatively simple predictive algebraic equations of motion possible.
  - **2.** He defined space and time in absolute terms, as "things" existing in their own right and with eternal, uniform natures. How could he know this?
  - **3.** He defined motion, too, in absolute, as well as in (Galilean) relative terms.
- **C.** Be careful here! The conceptual "ingredients" of Newtonian mechanics were, in effect, invented by Newton and were neither inductively nor deductively derivable from experience, but Newtonian mechanics works, and so does Newton's universal theory of gravitation.
  - **1.** Think about it: How could Newton know that the same force of gravity applies throughout the Universe? Can such a claim be justified experimentally? Empirically?

2. What Newton demonstrated, deductively, was that assuming his particular form of the gravitational force, he could accurately predict the orbits of the Moon and all the planets and the periodicity of Earth's ocean tides. In the process, he demonstrated that Kepler's three "laws" of planetary motion were necessary consequences of the force of gravity.
3. Reinforcing the claim that Newton's physics, notwithstanding its nonempirical definitions, gave us knowledge of reality was the 19th-century prediction of the existence of the planet Neptune based on deviations of the known planetary orbits from the values predicted by Newton's equation, as well as the roughly contemporary discovery that the orbits of binary stars observed Newton's equation.

II. Newton's physics works and, for more than 200 years, was lauded as finally giving man knowledge of at least physical reality, but Newtonian physics is wrong, in spite of "working"!

A. It is necessary to pay some attention to Newton's methodology as a physicist and the conclusions to which it led him.

1. Newton employed an "axiomatic method," together with a method of "analysis and synthesis," that he claimed allowed for the discovery of "true causes" of natural phenomena, as opposed to Descartes' method of "feigning hypotheses."
2. We cannot have knowledge without deduction; thus, a theory must incorporate premises that we either already know to be true or adopt as true.
3. Analysis and synthesis suppose that natural phenomena are composed of elementary constituents into which they can be decomposed, then recomposed, through some combination of experiment and conceptual analysis.

B. Newton's theory of light, expounded in his book *Opticks*, illustrates well his use of the method of analysis and synthesis.

1. Newton's prism experiments showed that sunlight can be decomposed into seven elementary colors, then recomposed into sunlight. The startling implication was that light was not a simple, "elementary", phenomenon, but a compound one.
2. Further experiments "revealed" many new facts about light that led Newton to formulate an "atomic" theory of light, complementary to the atomic theory of matter he already believed in on other grounds.

C. More than his theory of gravity, Newton's theory of light raised anew the question of the relationship between instruments and the phenomena they were used to study.

1. Did the prism reveal the "true" nature of light or did it distort light, causing the colors?
2. The mechanical calculator was invented in the 17th century, but it was not controversial in the way that the telescope and the microscope were.
3. Was Galileo seeing new realities, or interpreting "sights" produced by the telescope, and how can we check?

III. These questions lead us back to Newton's fundamental theory, of matter and its motions.

A. Are Newton's laws of motion facts about nature, or the consequences of the assumptions he made? Where did the assumptions underlying the three laws of motion come from?

1. Newton's mechanics worked, and made startling predictions that were confirmed, but are they true?
2. Newton's description of gravity as a force acting at a distance was intensely controversial on the Continent, where Descartes' mechanics, limited to contact forces only, held sway.

B. Newton was pushed especially hard on this point by Leibniz, who acknowledged that Newton's equations worked but rejected Newton's physical interpretation of them.

1. Newton backed off and separated his equations, experimentally confirmed, and his claims about the correlation of the terms in those equations with reality.
2. Newton and Leibniz were both *philosophers* of nature, not scientists in our sense of the term, and they had conflicting philosophies of nature.
3. Through a proxy, the Newtonian physician Dr. Samuel Clarke, Newton and Leibniz capped a long, bitter relationship by defending their respective and conflicting theories of God, nature, and reality

against one another.

- **C.** What did theory reveal of the nature of reality for these giants of modern science?
  - **1.** The Newtonian worldview is based on individual objects and the laws underlying their interaction.
  - **2.** The Leibnizian worldview is of a network of relationships.
  - **3.** Can theories give us knowledge of reality, given the Fallacy of Affirming the Consequent?

Recommended Reading:

Richard Westfall, *Never at Rest: A Biography of Isaac Newton*.

H. G. Alexander, ed., *The Leibniz-Clarke Correspondence.*

Questions to Consider:

1. What is an explanation? What do we need to know to feel that we understand something? Is the logical organization of facts enough?
2. What lessons are there in the historical fact that scientific theories can be accepted as knowledge for decades and even centuries, only to be set aside as “stories”?
3. How is it that God was central to the worldviews of the founders of modern science, yet modern science today is wholly atheistic, that is, allows no role whatsoever in nature for God?

Lecture Five

Science vs. Philosophy in the 17th Century

Scope: If extraterrestrials had visited Earth in 1400, they could not have predicted the emergence of modern science in the Christian culture of Western Europe. Yet by 1700, not only had modern science emerged there, but it was rapidly maturing in both explanatory power and cultural impact. In the course of the 18th century, science, and the Newtonian achievement in particular, would be held up as the justification for proclaiming the advent of an Age of Reason. What was happening in Western culture that both stimulated the rise of modern science and responded so strongly to it when it appeared? What did the early-18th-century nature philosophers actually *know* (about nature)? Inevitably, these questions call attention to the broader pursuit of knowledge at that time—not just in science but in philosophy and religion and in technology and politics—and to what people at the time meant by the word *know*. While the 17th century is often referred to as the era of the Scientific Revolution, it is also the century of the Thirty Years' War and the Treaty of Westphalia, of the English Civil Wars and the beheading of Charles I, of the Glorious Revolution of 1688 and the political philosophy that would be used to create the American Republic, and of the colonization of the Americas and a dramatic expansion of commerce and technology.

Outline

I. From the beginning, modern science utilized novel instruments that revealed realities we cannot experience directly. But the very novelty of these instruments raised questions about what it was that they revealed.

- **A.** Among the technological innovations affecting early modern science were the telescope, the microscope, the air pump, and the mechanical calculator.
  - **1.** The mechanical calculator was invented in the 17th century.
  - **2.** So were the telescope and the microscope, but the use of these raised deep questions that became more pressing as instruments became more complex.
  - **3.** The response to medical X-rays, and medical imaging generally, illustrates these problems well.
  - **4.** In the 17th century, it was the air pump, not the telescope or microscope, that is most revealing of the knowledge problems raised by new, experience-penetrating instruments.
- **B.** The air pump occasioned a philosophical "feud" between the Cartesian rationalist Thomas Hobbes, better known as a political philosopher, and the experimentalist Robert Boyle.
  - **1.** First of all, what does the air pump do, according to Boyle and Robert Hooke?
  - **2.** Second, what does it tell us that we didn't already know and that we can only know via the air pump? (Note: This is not a problem for the mechanical calculator, and though it was a problem for the telescope and microscope, a solution was believed available.)
  - **3.** Third, how do we know when it is working correctly, given that we cannot independently confirm the results of its operation?
- **C.** Who was Hobbes and what did he have against the air pump?
  - **1.** After reading Euclid, Hobbes became a Rationalist, sympathetic to Descartes' deduction-based mechanical philosophy of nature.
  - **2.** Hobbes opposed Baconian-style experimentalism, viewing all experiments as equivocal, and rejected the claim that the air pump *showed* us anything about reality.
  - **3.** Boyle, Hobbes argued, was simply interpreting results created by this machine in a way that was consistent with his own intellectual prejudices.
  - **4.** Hobbes argued that experimental instruments embodied assumptions linked to theories, and thus, their use could not provide independent confirmation of those theories.

II. There was another dimension to the Boyle-Hobbes controversy, one that challenged a foundational feature of the rapidly maturing early modern science more seriously than the rejection of the results of Boyle's air pump experiments.

- **A.** First of all, Hobbes was a philosopher, not a natural philosopher.

   1. Unlike Bacon, for example, Hobbes formulated a general theory of knowledge that he applied to claims by others of knowledge of natural phenomena, but this theory was neither derived from, nor motivated by, the study of such phenomena.
   2. Descartes and Leibniz also developed general theories of knowledge but they were explicitly adapted to achieving knowledge of nature, while in the 18th century, philosophers would develop new theories of knowledge because of modern science.

B. Hobbes was sharply critical of the Royal Society, of which Boyle was a founding member.

   1. Hobbes attacked the exclusivity associated with the society and its experimental demonstrations.
   2. The society was symptomatic of a major organizational novelty of modern science vis-à-vis philosophy, namely, the central role played by communal institutions through which researchers interacted with one another.

C. More broadly, Hobbes rejected the Royal Society's experimentalist approach to knowledge.

   1. Hobbes argued, following Descartes, that experiment was of limited value if one's goal is knowledge rather than the accumulation of interesting facts about the world.
   2. Experimental outcomes were intrinsically equivocal, that is, neither experiments nor the apparatus employed could tell us what the outcomes *meant*.
   3. Experiment cannot lead to knowledge of reality because experiments cannot unequivocally reveal causes. Knowledge of nature requires that we be able to deduce effects from causes and infer causes from effects.

D. What lessons for us are there in the Boyle-Hobbes controversy?

   1. Hobbes was ignored, but he asked important questions about the methodology of modern science and the bases of its knowledge claims, questions that were dismissed rather than answered. This is, by itself, an important fact.
   2. What we recognize as "good" science typically involves a production process keyed to experimentation and the use of specialized instruments that require training to use "correctly." This, at least, seems to make the object of scientific theories a construct of the scientific community, yet instruments often have undermined a community's theories.
   3. The production of scientific knowledge always involves contributions by gifted individuals, but the production process is intrinsically social, in the same sense that language is.

III. Hobbes defended a traditional Rationalist-philosophical definition of knowledge at a time (the 16th and 17th centuries) when knowledge had become problematic for society at large.

A. The Protestant Reformation was a 16th-century revolution in religion that influenced the 17th-century Scientific Revolution.

   1. The establishment of Protestant churches undermined the Roman Catholic Church's claim to privileged knowledge of God's word and will, but it created the problem of justifying the reformers' knowledge.
   2. The solution was the claim of a criterion of truth that was universal yet internal to the individual believer. Descartes secularized that criterion in order to overcome the revival of skepticism in the 16th century.
   3. Protestant theologians, among them, Joseph Glanvill (1636-1680), came to argue that philosophical "certainty" needed to be redefined to mean "certain enough" or "most reasonable" —because most probable—rather than logically necessary.
   4. This applied as well to knowledge of nature, as reflected in John Locke's influential Empiricist theory of knowledge, directly influenced by Newton's physics.

B. On the threshold of the self-proclaimed Age of Reason, which flaunted science as exemplary of the power of reason, what did the first scientists actually *know*?

   1. What was *known* about the Universe, the Earth, and man?
   2. Did anything that even the giants of 17th-century natural philosophy claimed to know about nature meet the demanding requirements of *knowledge*?

3. Was there, in 1700, a method of reasoning that guaranteed knowledge rather than opinion or belief? Given that the answer seems to be no, why did science make such a big impression on the greatest minds of the 18th century?

Recommended Reading:

Basil Willey, *The Seventeenth-Century Background*.

Steven Shapin and Simon Schaffer, *Leviathan and the Air Pump*.

Questions to Consider:

1. If the construction of complex instruments is based on currently accepted theories, how is it that such instruments can produce data that overturn those very theories?
2. Was it coincidental or was the emergence of modern science an expression of developments within Western culture that tie modern science to Western cultural concepts and values? What difference does it make?

Lecture Six

Locke, Hume, and the Path to Skepticism

Scope: Seventeenth-century science was accessible to a much wider audience than science today is, in part because the language of scientific discourse was not yet as specialized, technical, and abstract as it became in the 19th century. In part, though, 17th-century science reached and affected a wide audience precisely because it was still natural philosophy, and *as* philosophy, it was of broad intellectual concern. Even those who did not fully understand the mathematics in which the new physics was couched were able to understand the underlying concepts and their philosophical implications. John Locke, for example, developed a theory of knowledge consistent with what he took to be the strictly Empiricist basis of Newtonian science. Although he worded it carefully, Locke had to conclude that certainty was not possible for truly experimental science. Concurrently, Anglican Bishop George Berkeley, born and raised in Ireland, saw atheistic materialistic determinism as the inevitable consequence of Newtonianism and launched a vigorous attack on its foundations. The Scotsman David Hume pushed Locke's theory of knowledge one step further and, extending Berkeley's critique of the new science to the concept of cause, developed a skeptical theory of knowledge in which science can give us only probable knowledge of nature.

Outline

I. John Locke, inspired by the impact of Newton's physics, formulated the classic *modern* Empirical theory of knowledge, in explicit contrast to the Rationalism exemplified by Descartes.

- **A.** Whatever their philosophical differences, the new natural philosophers shared a number of ideas relevant to any theory of knowledge.
  - **1.** These included the ideas that all our knowledge of the world came from the world via the senses and that sensations fell into two classes, primary and secondary, respectively, *objective* and *subjective*.
  - **2.** The problem posed by deriving knowledge from empirical experience is that experience is particular, while knowledge is defined to be universal.
- **B.** In his *Essay Concerning Human Understanding*, John Locke asked: What can the mind know, and how does it know it?
  - **1.** Knowledge is constructed by the mind's discovery of agreement or disagreement among its ideas, none of which is innate.
  - **2.** Because knowledge is a relationship among ideas, it is in principle capable of being universal, necessary and certain, but only insofar as it is internal to the mind.
  - **3.** But the simple ideas in the mind, being the effects of primary sensations, come from the world outside the mind.
  - **4.** Things in the world have causal "powers" to produce our primary sensations of things "out there" and of their actions on one another.
- **C.** What, then, is knowledge, for Locke? It is a "perception" by the mind of the agreement or disagreement among our ideas and their connections with one another.
  - **1.** Locke argued that careful reflection on experience, separating primary and secondary sensations, in the form of controlled experimentation and logical reasoning, allows us to *know* that there are objects external to us, possessing distinctive "powers" to act on us and on one another in regular, lawful ways.
  - **2.** This knowledge is not demonstrative; it cannot be as certain as the knowledge we have of our own existence or of mathematics, but it is "certain enough" for all our needs.
  - **4.** Action would be impossible if it required universal, necessary, and certain knowledge.
  - **5.** Empiricists talked knowledge of nature, but redefined "knowledge" to be less than certain!

II. Bishop George Berkeley mounted a vigorous attack on the "new" science.

- **A.** Although Berkeley accepted Newton's mathematical equations as correct *descriptively*, he rejected the physical interpretation of these equations in terms of forces exerted by matter.

    1. Berkeley saw that Newtonianism entailed materialistic determinism; that is, it led to the reduction of all natural phenomena to matter in motion, whose laws it was science's goal to discover.
    2. The concept *matter* was, thus, foundational to modern science, and Berkeley believed it was vulnerable to a withering criticism.
    3. Modern science, he argued, claims to be strictly empirical, but the role of matter in science is that of a metaphysical principle, not a fact of experience.
  - **B.** What role does matter play, in nature and in scientific explanation?
    1. *Matter* is a name for that which causes sense experience and, thus, is the cause of all the simple Lockean ideas. But we never experience matter, only its effects. We are sure that these effects have an external cause, but we only assume that the cause is matter!
    2. Lacking any experience of matter as a causal agent, Berkeley concluded that *all* sensations, primary no less than secondary, were in the mind, just as all ideas of reflection are.
    3. One of these reflective ideas happens to be that something outside the mind must be the agent causing those ideas we discriminate as sensations.
    4. We might just as well identify this causal agent as God rather than as a mysterious, intrinsically inert, unexperienced stuff called *matter*.

- **III.** David Hume developed an explicitly skeptical theory of knowledge of nature based on his critique of causality.
  - **A.** Hume was an enthusiastic Newtonian while rejecting the claim that Newton gave us universal, necessary, and certain knowledge of the world external to mind.
    1. Hume argued that causal relationships were ideas in the mind, not facts about the world.
    2. We have no experience of causal connection among the matters of fact that make up our sense-derived ideas of the world—and can have no such experiences.
    3. It follows that we cannot have knowledge of matters of fact and their relationships, but only knowledge of our own ideas, as in mathematics.
    4. We cannot, therefore, be certain of the truth of any statement we make about the world. Scientific theories may take a logically necessary form, but they are, inescapably, only probable.
    5. We can have knowledge in mathematics, and in games, because we make up the definitions/rules from which we deduce theorems/moves that follow from those definitions/rules.
  - **B.** Hume revealed the skepticism hidden within Lockean Empiricism.
    1. Skepticism has been marginalized in Western philosophy since the time of the ancient Greek thinkers and is often linked to amoralism: an "anything goes" philosophy of life.
    2. Hume emphatically rejected the radical ancient form of skepticism that rejected all knowledge claims whatsoever.
    3. What Hume embraced was Academic Skepticism, championed by the Roman philosopher Cicero, who argued, as the Sophists had, that we could only achieve probable knowledge of experience but not necessary knowledge.
  - **C.** Hume's critique of inductive reasoning poses a challenge even today.
    1. On the basis of what evidence do we suppose that past experiences will be repeated in the future?
    2. A cause, for Hume, names a uniformity we have observed in experience, but there is no logical basis for projecting it onto future experiences, only a "habit" of mind, a feeling.
    3. Throughout this analysis, it must be kept in mind that for philosophers, "cause" means a necessary and sufficient condition for an effect.

Recommended Reading:

John Dunn, J. C. Urmson, A. J. Ayer, *The British Empiricists.*

Roy Porter, *The Creation of the Modern World: The Untold Story of the British Enlightenment.*

Questions to Consider:

1. Given that all perception takes place within the mind, how do we distinguish what is "really" outside the mind from what is "only" inside and get it right the majority of the time?
2. If Berkeley is correct that matter is a metaphysical concept, then what does making matter a foundational concept of empirically grounded modern science (in spite of Berkeley's critique!) reveal about the values of modern scientists?

Lecture Seven

Kant Restores Certainty

Scope: Kant's ambition was to be what we would call a physicist. Among numerous publications throughout his life on mechanics and mathematics, one stands out as emblematic of what Kant thought was a reasoned scientific theory: his theory of the Universe and the origin of the Solar System. When, in middle age, he finally received a full university appointment, Kant set aside a scientific career to respond to Hume's philosophical works, which he greatly admired. Hume's conclusion that we could have only more or less probable opinions about nature but no knowledge in the strict philosophical sense was unacceptable to Kant. There *was* knowledge of nature for Kant, and Newtonian physics was exemplary of it. Yet Hume's critique of causality and necessity as merely ideas and not attributes of reality was convincing to Kant and could not be dismissed. Kant, therefore, set himself the task of rescuing knowledge while admitting the correctness of Hume's critique! Ten years later, the solution he worked out appeared as *The Critique of Pure Reason*. It was breathtaking in its boldness, originality, fertility, and its impact on the subsequent course of Western philosophy. Kant invented a philosophical system that guaranteed universal, necessary, and certain knowledge but at a price. We could have knowledge of experience but not of the world as it "really" is, beyond experience.

Outline

I. Immanuel Kant was first a committed Newtonian natural philosopher, but then devoted himself to defending Newtonian physics as true knowledge of nature against Hume's skepticism.

- **A.** Kant's *Universal Natural History and Theory of the Heavens* was published in 1755 but was largely ignored for 60 years.
  - **1.** Kant's starting point was Thomas Wright's *Original Theory or New Hypothesis of the Universe* (1750), based on Newtonian science and mathematical principles.
  - **2.** Among other claims, Wright argued that the Universe was infinite, that the Milky Way was a vast disk composed of an enormous number of stars, each of which has a sun like ours at the center of a planetary system like ours and that the Universe was comprised of an infinite number of such Milky Ways.
- **B.** Kant extended Wright's theory/hypothesis and addressed at greater length the methodological issues underlying the knowledge claims he made.
  - **1.** Kant used Newton's physics to argue that stars and planetary systems form out of clouds of gaseous material.
  - **2.** Stars cluster to form galaxies centered on a mega-star; galaxies cluster in an endless cosmic hierarchy.
  - **3.** Kant emphasized that he was proposing a strictly mechanical explanation of cosmological phenomena, subsequent to God's initial act of creation.
  - **4.** He proposed a dynamic, continually expanding Universe, infinite in space and time, composed of a hierarchy of gravitationally bound stars and galaxies.
- **C.** Kant acknowledged that "mathematical infallibility" was not possible in cosmology.
  - **1.** Using analogies and "correct reasoning," however, together with Newtonian mechanics, we can come close to "infallibility", especially if new data corroborate the theory's predictions.
  - **2.** Kant deduced the axial rotation of Saturn from his model of the solar system and argued that if future astronomers confirmed his prediction (of a little more than 6 hours), then that would confirm his theory of the cosmos as well.
  - **3.** Note that this is an illustration of the Fallacy of Affirming the Consequent in action!

II. Kant's fame, of course, rests on his accomplishments not as a scientist but as a philosopher.

- **A.** Kant received his first paid university appointment at 46, in 1770. It was then that he first read Hume carefully and realized the threat he posed to scientific knowledge.

    1. Kant was unshakeable in his conviction that we had knowledge of experience, knowledge that was universal, necessary, and certain.
    2. But having such knowledge of experience requires the universal, necessary, and certain truth of some statements about experience.
    3. In his *Critique of Pure Reason*, Kant explained how this was possible.
  - **B.** Kant responded to Hume by proposing a "Copernican revolution" in philosophy.
    1. As Copernicus had exchanged the positions of the Sun and the Earth, so Kant reversed the roles of world and mind in knowing.
    2. Traditionally, philosophers assumed that our experience of the world was passive: the senses passively respond to stimuli.
    3. Kant now argued that experience is actively constructed by the mind in strict accordance with innate rules.
  - **C.** How does the mind construct our experience of the world?
    1. We begin with the sensory forms, or "intuitions", of space and time that are the bases of geometry and arithmetic.
    2. Euclidean geometry is the only possible geometry we can think of, it is thus necessarily true of space, because it is the only way we can conceptualize space.
    3. This is true of mathematics generally, and it exemplifies Kant's central philosophical innovation: synthetic *a priori* judgments.
    4. Further, Kant identified 12 concepts, "categories of the understanding," that were the only concepts we could have in reasoning about experience.
    5. It follows that Newtonian physics is universally, necessarily, and certainly true because it expresses the way the mind "works."

- **III.** Kant's "transcendental" philosophy identifies how we can know, what we can know, and what we can only assume based on what we can know.
  - **A.** Kant "solved" his knowledge problem by switching the cause of experience from external objects to the mind itself, but his genius lay in working out in detail the means by which the mind does this.
    1. Kant employed a kind of reverse deductive reasoning to identify what the mind needed to be like in order for the mind to possess true knowledge of experience, in the strict sense of "knowledge".
    2. Kant answered Hume, but at a steep price: we cannot have knowledge of the world as it is beyond experience.
    3. Kant was not a solipsist: he deduced from his system that there was a world beyond experience, but what that world was like was not knowable by us *because of* the self-activity of the mind.
  - **B.** Has Kant answered Hume and refuted his skepticism about knowledge?
    1. If our universal, necessary, and certain knowledge is not of the world as it is prior to the way we experience it, then doesn't Hume win?
    2. Like Hume, Kant concluded that we have grounds for believing propositions about the world, but we cannot know the truth of these propositions.
  - **C.** Kant's theory of knowledge was soon proven to be wrong, but his system was influential nevertheless, especially on our problem of what scientists know.
    1. The invention of non-Euclidean geometries was a blow to Kant's system.
    2. More generally, the ahistoricity of the intuitions and categories of understanding was increasingly at odds with historical development, which was a core theme of 19th-century physical, life, and social science.
    3. Kant's Idealist theory of knowledge led to a school of philosophers, most prominently Hegel, whose Idealist philosophies of reality were of great influence in the 19th century.
    4. More to our point, Kant influenced many thinkers who attributed an active role to the mind in determining what we mean by knowledge, truth, and reality.

    5. Ironically, this, too, brought Hume into the limelight, because of Hume's "associationist" theory of how the mind works.

Recommended Reading:

Immanuel Kant, *Universal Natural History and Theory of the Heavens.*

Manfred Kuehn, *Immanuel Kant: A Life.*

Questions to Consider:

1. In what sense was Kant's cosmological theory a *scientific* theory, as 19th-century astronomers, who are highly respected today as scientists, thought it was?
2. If the mind plays an active role in structuring experience and how we reason about it, how is knowledge for Kant different from what it was for Hume or even Locke, namely, a matter of the agreement or disagreement of ideas?

Lecture Eight

Science, Society, and the Age of Reason

Scope: The role that scientific knowledge plays in society today is the realization of an 18th-century vision linking social reform and the idea of progress to reason by way of science. Thomas Paine proclaimed an Age of Reason in support of the American colonists' assertion of a right to use reason to create a new government, based on "self-evident" truths. Kant proclaimed that he lived in an age of enlightenment, an age in which reason was increasingly recognized as the basis for ordering human affairs. A central theme of the French Revolution was the rationalization of social relations, which required freeing society of the irrational influence of religion and inherited power. That people not privileged by birth could acquire knowledge that would advance human well-being, individually and socially, was central to the social, political, and economic reform movements of the 18th century. The evidence supporting this claim was in plain view: the growth in scientific and mathematical knowledge and in technological innovation from the 17th through the late 18th centuries. Although Newtonian science did evolve into a materialistic determinism, as Berkeley foresaw, it nevertheless became the cornerstone of social reform movements because it was perceived as embodying the power of reason and proof of the reality of progress.

Outline

I. The Enlightenment vision defines what we mean by modernity.

- **A.** The pursuit of knowledge had taken a new turn in the 17th century.
  - **1.** Descartes argued that only in mathematics, because of the deductive character of its reasoning, did we actually possess knowledge.
  - **2.** Philosophers had yet to achieve anything they knew with certainty in spite of almost 2,000 years of trying.
  - **3.** The claim to knowledge in religion was controversial and rested on claims of revelation, not reason.
  - **4.** Modern science proposed effective ways of achieving knowledge of nature using reason.
- **B.** By the 18th century, belief in the idea of progress was commonplace, and science and technology were among its principal supports.
  - **1.** Knowledge of nature became associated with progress and improvement by the 18th century, though initially the credit belonged to technology.
  - **2.** Historically, technology "leads" science in terms of social impact and useful innovations until the late 19th century.
  - **3.** Seventeenth-century innovations in science and mathematics were important factors in the public identification of the new reason-based natural philosophy with human progress, but progress was a Renaissance idea, built into Renaissance Humanism and a controversial idea well into the 17th century.

II. Newtonianism evolved in the course of the 18th century into the perceived embodiment of reason and of the lawfulness of nature.

- **A.** Newton's triumphant gravitational theory and mechanics inspired the application of reason in the scientific manner to all aspects of experience, from psychology to economics.
  - **1.** Montesquieu pioneered the natural philosophical approach to analyzing social relationships and institutions, essentially founding sociology.
  - **2.** The American revolutionaries argued that reason was all that was needed to create the optimal form of government and society.
  - **3.** Hume the Frenchman Condillac pioneered the application of a kind of "mechanics" to the mind.
  - **4.** Turgot and his disciple Condorcet applied mathematics-based reasoning to political decision-making and Adam Smith, in his *The Wealth of Nations*, applied reason to economics.
- **B**. The 18th century identified itself as an age of reason.
  - **1.** Reason is promoted, and perceived, as a universal problem-solving tool.

        2. Science, reason, and progress are conflated: Mankind progresses through the application of reason to our understanding of, and action on, the world.
        3. Kant proclaimed an age of "enlightenment."
        4. Thomas Paine's *The Age of Reason* was a best-seller and very influential.
    - **C.** European society was astonishingly receptive to the rise of modern science and it is not at all clear why.
        1. It is not clear whether the impact of modern science on 18th-century Europe was cause or effect.
        2. The rise of modern science may have caused the spread of secular and materialist values (as Berkeley had feared), or it may have been an expression of the independent, earlier emergence of such values in the 16th and 17th centuries?
        3. Of particular interest was the emergence of an aggressive materialistic determinism as a scientific truth.
        4. The French Newtonian Laplace epitomized this aggressiveness in his comment to Napoleon that he "had no need" for the hypothesis "God" in his magisterial extension of Newton's theory of the Solar System.

- **III.** The cultural impact of scientific knowledge took many forms, some of them subversive of the social status quo, as science and reason became tools for social reform in spite of determinism.
    - **A.** One subversive influence of science was action spurred by the idea that knowledge was power.
        1. The French *Encyclopédie*, edited by the philosopher and writer Denis Diderot, aimed at publishing accounts of all contemporary technologies, a clear attempt at giving power to the people.
        2. The French Revolution of 1789, even as it sank into bloody chaos, retained its commitment to reason as the key to social reform.
        3. One manifestation of this commitment was the support for "rationalizing" the nation's system of weights, measurement, and timekeeping by mandating uniform, universal standards.
    - **B.** Giving know-how, technological knowledge, to the people threatened the political and economic status quo; thus, the *Encyclopédie* was repeatedly attacked by the monarchy and the craft guilds.
        1. To the reformers, though, undermining the status quo opened the way to progress. It is interesting to compare the *Encyclopédie* to contemporary British encyclopedias, which collected knowledge, but not know-how.
        2. The transformational power of reason was reinforced by such industrial innovations as the factory system of production, mass-production machinery, a useful steam engine, and the emergence of civil (as opposed to military) engineering.
    - **C.** The spread of science, however, also provoked a reaction.
        1. There is a certain irony to a deterministic theory of reality becoming the cornerstone of social reform.
        2. Jean-Jacques Rousseau argued that science and technology were making life worse, not better.
        3. People were becoming increasingly distant from the "state of nature" that would make them happy.
        4. Rousseau influenced the emergence of the Romantic movement in the late 18th and early 19th centuries, whose members argued, in poems, plays, novels, and essays, that Man needed to live by feeling primarily rather than by reason.
        5. The Romantics—among them, Goethe, Blake, Novalis—claimed that the best life was one guided by heroic feeling, not calculating reason, and that happiness was not the ultimate human value.

Recommended Reading:

Peter Gay, *The Enlightenment.*
Thomas Hankins, *Science and the Enlightenment.*

Questions to Consider:

1. How can a rigorously deterministic theory of reality motivate reform?
2. The historian Lynn White wrote that a new invention opens a door, but it doesn't compel anyone to walk through it. What is revealed by the breadth and depth of the 18th-century rush through the door opened by the new invention called "reason"?

Lecture Nine

Science Comes of Age in the 19th Century

Scope: The promise of scientific knowledge began to be realized in the 19th century. Quite suddenly, 200 years after the claim that knowledge of nature would yield power over nature, scientific knowledge began to converge with technological innovation. Electrical and electromagnetic theory, thermodynamics, the germ theory of disease, and organic and structural chemistry underlay the creation of whole new industries, from telegraphy and commercial electricity to synthetic dyes and pharmaceuticals, that generated immense wealth and initiated a transformation of society. But especially in physics—for many, the archetypal science—the form of the new theories became increasingly mathematics intensive. And in virtually all the natural sciences, the content was keyed to entities visible or detectable only using increasingly complex instruments, invented and constructed in accordance with scientific theories. In spite of science's growing applicability to the "real world," then, which would seem to be proof enough that the object of science was reality, scientists themselves began to question the relationship between theories and reality. This questioning began even before the invention of non-Euclidean geometries sundered the 2,300-year assumption of a direct connection between deductive—hence universal, necessary, and certain—reasoning and knowledge of reality.

Outline

I. What is the object of a scientific theory, that is, what is a theory about?
  A. What are the possible choices for what theories are about?
    1. On the face of it, theories are descriptions of nature. They reveal to us the way things "really are" out there, as opposed to the way that we experience things.
    2. Astronomers tell us that, experience notwithstanding, the Earth is "really" moving very rapidly and in very complicated ways, as described by Newtonian theory (out of Copernicus by way of Kepler).
    3. Similarly, I experience my body in a way that biologists assure me has nothing whatsoever to do with what is "really" going on in my body, which their theories describe in terms of molecular processes.
    4. I think I am seeing a world "out there" when I open my eyes, but vision theory tells a very different story, which, again, is asserted as the "truth" of the matter, as what is "really" happening when light reaches my eyes.
  B. But must we conclude that because theories "work" that they correspond to realities beyond experience?
    1. It is common for rival theories to be proposed for the same phenomena, either concurrently or consecutively.
    2. This forces us to choose between these theories, because conflicting theories cannot both be true of reality, but this poses the problem of the criteria to use in pronouncing one theory true and its rivals false.
    3. Francis Bacon's response was that the criterion of truth is results, and this is curiously similar to the criterion of spiritual truth proposed by the Protestant Reformer Calvin.
    4. But a theory can "work" in its own time, can make confirmed predictions and give satisfying explanations, yet be judged wrong at a later time, so the object of theories may be experience rather than a reality beyond experience.
    5. It is the claim that theories are true accounts of reality that makes scientific knowledge problematic.
  C. A valuable illustration of this point is heat. What *is* heat?
    1. Around 1800, a standoff existed between the caloric theory that heat was a weightless fluid and the theory that heat was motion.
    2. Benjamin Thomson, who took the name Count Rumford, performed a famous experiment, one that he thought was a "crucial" experiment, capable of settling the issue once and for all in favor of the claim that heat was motion.
    3. The experiment, though it was successful, did no such thing, and the controversy continued!

    4. In 1822, however, Joseph Fourier published a mathematical theory of heat that explicitly rejected taking a position on what heat *was* and "simply" described how heat *behaved* in solid bodies.
    5. What Fourier's equations described was real, but the success of the equations was independent of any claims about the constitution of reality (of what heat was or, for that matter, of what matter was). This proved to be an epochal and highly controversial move in 19th-century physics.

II. Before tracing the significance of Fourier's move for 19th-century science, we need to take account of a related intellectual bombshell.

- **A.** After 2,300 years, the assumed connection between deductive reasoning in mathematics and reality was severed.
    - **1.** Recall that for at least 2,300 years, Euclidean geometry had been the exemplar of *knowledge* of reality, in this case, knowledge of spatial relations.
    - **2.** We knew that all of its theorems were true because each was the conclusion of a valid, deductive logical inference from premises that were themselves either conclusions of such arguments, or were self-evidently true.
    - **3.** Euclidean geometry in particular (and mathematics in general) was taken as proof that knowledge in the sense of universal, necessary, and certain truths about reality was possible and was the model for knowledge of anything.
- **B.** Non-Euclidean geometries made the connection between deductive reasoning and reality nonlogical.
    - **1.** Beginning in the 1820s, several mathematicians independently formulated geometries that were deductively valid, yet whose theorems differed from one another and from Euclidean geometry.
    - **2.** The inescapable conclusion was that deductive reasoning has no *necessary* connection with knowledge of reality!
    - **3.** Euclidean geometry would be true of space if and only if the definitions, postulates, and axioms on which its deductive reasoning was based were true of space.
    - **4.** Euclid thought their truth was self-evident. He was wrong, but the generic lesson was that the truth of claims that the object of a theory is reality depends on the correspondence to reality of the assumptions on which the theory rests.
- **C.** The eruption of non-Euclidean geometry made the connection between geometry and physics empirical rather than logical.
    - **1.** We cannot distinguish between alternate geometries on logical grounds with respect to their physical truth.
    - **2.** But if the connection between geometry and physics, between mathematical models and scientific theories, is empirical then the ground is cut from under the claim that scientific knowledge is universal, necessary, and certain.
    - **3.** There is an echo here of Fourier's move in his theory of heat.
    - **4.** In science, deduction remained the preferred form of reasoning for *presenting* a theory, but it was now clear that the truth of a theory in the sense of correspondence with reality was deeply problematic. On the face of it, theories were only "true" relative to a set of assumptions, which themselves were justified not by derivation from experience but by the claim that the theory "worked."

III. These developments legitimized several questions, among them: What are scientific theories about? What makes a theory true? What assumptions are reasonable ones for a scientist to base a theory on?

- **A.** What assumptions should a theory be based on, and where do assumptions come from?
    - **1.** Consider typical assumptions of early-19th-century Newtonian science: the conservation of matter and momentum, the inertia of matter, the featurelessness of space, and the uniformity of time.
    - **2.** Can we know the truth of these assumptions? Was their truth established before they were made assumptions? Could we know their truth?
    - **3.** Recall Descartes' methodology of inventing hypotheses that are justified by deriving phenomena from them and Newton's rejection of "feigning" hypotheses in favor of his own method of inferring assumptions from experiment in order to uncover "true causes" of phenomena.

B. What makes a scientific theory true?

  1. Logically, the gulf between induction and deduction is unbridgeable. Neither experience nor experiment can establish with certainty the truth of a universal proposition.

  2. Assumptions cannot be deduced from experience. They must be arrived at in some way and proposed as universal assumptions about nature in order to explain experience.

  3. There is an echo here of Fourier's move and a sharp focus on the question of where assumptions come from and how they are to be justified.

Recommended Reading:

Peter M. Harman, *Energy, Force and Matter: The Conceptual Development of Nineteenth-Century Physics.*

Mary Jo Nye, *Before Big Science.*

Questions to Consider:

1. What difference does it make if science is about reality or about our experience of reality?

2. Given how well science works and that it works better and better over time, how can it not be about the way things really are?

Lecture Ten

Theories Need Not Explain

Scope: Nineteenth-century developments in science—thermodynamics, electromagnetic theory, the kinetic theory of gases, and the Darwin-Wallace theory of evolution by natural selection—and in mathematics compel the question: What is a scientific theory *for*? Is the purpose of a theory explanation, prediction, and control of experience or revelation of reality? Is a theory an abstract, idealized "picture" of reality or a description of how some cluster of related phenomena behave and interact with other phenomena? What difference does it make if we answer one way or another? Fourier and others showed that a theory can give us prediction and control without telling us about realities "behind" experience. But then as now, the dominant view of scientific knowledge, both within the science community and among the general public, was that scientific theories *are* in some sense "pictures" of reality, that they *do* reveal what is "out there," and that explanation and understanding are primary goals of science. But non-Euclidean geometries reveal that explanation and understanding cannot be solely a matter of logic, which raises the odd-sounding questions: How does an explanation explain? What does it mean to understand something?

Outline

I. With what I have been calling Fourier's move, the claim that a scientific theory is a picture of a reality is suddenly called into question.

- **A.** A theory that works empirically without offering a "picture" of reality forces us to clarify what a theory is for.
  - **1.** Is it enough for a theory to predict and, at least in principle, to control the course of future experiences, or must a theory also, and perhaps primarily, explain?
  - **2.** Recall that from Adelard of Bath on, it was taken as a given that the task of natural philosophy is to explain natural phenomena as the effects of natural causes, increasingly, in terms of hidden causes.
  - **3.** Recall, too, that by the 18th century, causal explanation in natural philosophy was understood to be deterministic explanation, as affirmed by Laplace at the turn of the 19th century (in spite of Hume's critique of causality).
  - **4.** Thus, causal explanation in science mirrors logical explanation in mathematics.
  - **5.** In both cases, deduction is the key to explanation.
- **B.** The emergence of non-Euclidean geometries in the mid-19th century complicated matters by making the connection between logical reasoning and experience an empirical, rather than a deductive logical, connection.
  - **1.** It follows that a theory in which phenomena are the logically necessary consequences of premises and principles does not necessarily reveal truths about the world.
  - **2.** This problem, so to speak, is the justification for the specific definitions, assumptions, and "principles of nature" that enable universal theories/laws—from which phenomena can be deduced as necessary consequences.
  - **3.** The history, especially from Lavoisier in the 1780s on, of the principle of the Conservation of Matter illustrates this problem well.
  - **4.** Relativity theory forced a reformulation of this principle and on several occasions physicists proposed abandoning it in order to protect quantum theory.
  - **5.** Indeed, these latter episodes provide deep insights into how scientists make assumptions and why.
- **C.** The subsequent development of 19th-century mathematics created a problem for mathematics exactly like the one Fourier created in physics.
  - **1.** Do mathematical objects exist independent of the human mind, or are they created by the mind?
  - **2.** If they exist independently of the mind, then how do we know them at all?
  - **3.** If we invent them, the way we invent games, for example, then the astonishing applicability of mathematics to experience is "miraculous."

    4. Although this question remains unanswered today, new mathematics continues to be created and to be applied by scientists, without clarifying what mathematics is about!

II. Part of the richness of 19th-century science comes from the growing recognition among scientists of the historical dimension of scientific theories.

- **A.** To say that theories generically are historical entities is not merely to say that they have a past, but that development over time—I would say evolution—is essential to what theories are.
    1. Consider Copernicus's theory, which we consider to be right even though it is all wrong!
    2. It was Kepler who "corrected" Copernicus—replacing circular orbits with elliptical orbits, and uniform speeds with nonuniform speeds; also adding two solar forces that kept the Solar System moving as it did and a mathematical account of its structure.
    3. And it was Newton, 70 years later, who finally got it "right."
- **B.** The *evolution* of the Copernican theory has features that are typical of scientific theories. It is normal for scientific theories not simply to change in details over time but to change in ways that are fundamental.
    1. Newton's mechanics and theory of gravity appeared to be permanent, true forever.
    2. This was reinforced by Laplace's extension of Newton's physics in his *Celestial Mechanics* (and by the successful prediction of the existence of the planet Neptune, based on deviations of the motion of Uranus from values predicted by Newton's equations).
    3. However, with the general theory of relativity in 1915 and the expansion of the Universe in 1929, the Newtonian picture of the Universe evolved into the Big Bang theory in the late 1940s.
    4. And the Big Bang theory morphed into Alan Guth's inflationary theory in the 1980s.
- **C.** Scientific theories on the classical view are "true" and, as such, are not expected to have a history or change over time, but in fact they do and not just by unfolding: Theories evolve.
    1. Recognition of the historicity of scientific theories was a major development in the 19th-century understanding of the nature of scientific knowledge.
    2. One contribution to this new understanding was recognition of the changing assumptions scientists adopted in response to changing experience.
    3. Through the introduction of new or improved instruments, experience is effectively always changing and, with it, the need to modify assumptions.
    4. Theory change and the historicity of theories are, thus, "natural"!

III. While physical scientists were beginning to become conscious of the historicity of scientific theories, the theory of evolution introduced historicity into nature itself.

- **A.** The Darwin-Wallace theory of the evolution of life forms by natural selection acting on spontaneous variation is, from the current perspective, a particularly important one to understand *as an instance of a scientific theory*, setting aside for the moment the question of its correspondence with reality.
    1. I limit myself here to 1858–1859, the years in which Wallace sent his essay on evolution of species to Darwin, and Darwin published *On the Origin of Species*.
    2. The Darwin-Wallace theory must be understood in the context of 19th-century theorizing within science and about science.
    3. In physical science, as expressed in its causal determinism, time in and of itself plays no causal role, but in evolutionary theory, true novelty, unpredictable biological novelty, emerges in time.
- **B.** Let's begin with Wallace's astonishingly compact 1858 essay "On the Tendency of Varieties to Depart Indefinitely from the Original Type."
    1. Wallace's argument is qualitative and simple to follow. It is not at all dependent on fossil evidence and is based on Wallace's wide knowledge of the geographical distribution of plants and animals, birds and insects.
    2. It is indisputably the case that all organisms vary from their parents, typically in minute ways but sometimes in major ways, and that plants and animals produce more offspring than could possibly survive. This leads to a "struggle for existence" that guarantees that individuals whose variations from

their parents and peers happen to confer a survival advantage will out-reproduce them, causing the population to diverge over time from the "original type."

  3. The process of variation is continual and so is the process of "passive" selection relative to the environment. Furthermore, the divergence is strictly a function of environmental change and, in principle, unlimited.
  4. The central conclusion of this argument is that the term *species* is a name for a relatively stable population that, in fact, is continually changing over long periods of time.
  5. The broader conclusion is that people routinely classify phenomena in ways that they take to be natural rather than conventional.

- **C.** Wallace's essay was a shock to Darwin, who recognized that Wallace's argument was essentially his own argument, one that he had been spending 24 years amassing data to support.
  - **1.** Darwin and Wallace both had read Thomas Malthus's essay on population growth, and both suddenly "saw" that the struggle to survive in a changing environment implied that *species* was a name for a temporarily stable population of varieties.
  - **2.** For both, the primary evidence was biogeography, not the fossil record.
- **D.** In the course of the 19th century, history became a central internal feature of theories of Earth, life, mankind, culture, language, and society.
  - **1.** The history of science emerged as a scholarly discipline in this period, but the truly important intellectual development was recognition that natural phenomena, and their explanation, were intrinsically historical. The Darwin-Wallace theory played a major role in this through the attention it attracted.
  - **2.** This development further highlighted the role played by assumptions in formulating scientific theories, but it also led to a realization that science was a collective enterprise.

Recommended Reading:

Charles Darwin, *The Origin of Species.*

Michael T. Ghiselin, *The Triumph of the Darwinian Method.*

Questions to Consider:

1. What does it mean to understand something?
2. How can we tell if a classification system uniquely identifies features of reality or reflects aspects of reality that interest us? Consider: Is there a uniquely correct way to classify 10,000 books delivered to your house as your legacy from an eccentric uncle? How about 100,000 specimens of insects, plants, and animals that no one has ever seen before?

Lecture Eleven

Knowledge as a Product of the Active Mind

Scope: On the commonsense view that the senses are passive, we experience the world pretty much as it is. However, the distinction between primary and secondary sensations meant that the senses were *not passive*, so that experience was *not* of nature as it was in itself, though both were supposedly strictly correlated. Thus, the core task for modern science became correcting the distortions introduced by the senses in order to discover what was "really" out there and how it caused experience. But what if the mind and, perhaps, reasoning as well are not passive as they attempt to decode the encrypted messages about the world transmitted by the senses? What if they actively influence what we reflect on and how we reason, analogous to the way the senses influence our response to external stimuli? How is knowledge of nature then possible? Kant's theory of an active mind is one of a class. What is common to them is that there are features of conscious experience and reasoning about it that originate in the mind and not in the world. If so, we cannot mean by *knowledge*, *truth*, and *reality* what the founders of modern science wanted to mean by those terms.

Outline

I. What happens to knowledge, truth, and reality when you add an active role for the mind to an active role for the senses?

- **A.** William Whewell was the first "scientist" (because he invented the word!), and he expended a great deal of effort on the problem of scientific knowledge.
    - **1.** Aristotle assumed that the senses do not distort what they receive from "out there" by imposing their own natures on their stimuli, but by the 17th century it was a commonplace view that secondary sensations were produced by us and did not exist in the world.
    - **2.** This implied that the mind, via reason, needed to distinguish what was *really* out there from what only *seemed* to be out there.
    - **3.** Kant had made an issue out of an originary role for mind and, for some, this led unacceptably to Idealism, but it was hard to dismiss the skeptical implications of Empiricism.
    - **4.** The mind's self-activity in responding to sense experience was what Bacon had been afraid of and invented his experimental methodology to control.
    - **5.** Fourier's move, however, was symptomatic of a growing suspicion that scientific theories were in some sense inventions rather than uncoverings of what was already "there."
- **B.** Between 1830 and the mid-1840s, Whewell published two large works on what scientists know and how they know it: *A History of the Inductive Sciences* and *The Philosophy of the Inductive Sciences Based on Their Histories.*
    - **1.** Whewell argued that the *form* of scientific knowledge was deductive, deducing phenomena from the premises of theories.
    - **2.** The key to generating knowledge of nature lay in identifying "fundamental ideas" consistent with experience that can be made explanatorily fertile premises of deductive arguments.
    - **3.** Whewell's fundamental ideas differ from Kant's categories because they are historical, and from Descartes' invented hypotheses because they are "induced" from experience.
- **C.** To rescue universal, necessary, and certain scientific knowledge of nature, Whewell redefined *induction.*
    - **1.** Whewell argued that induction was more complex than mere accumulation and analysis of experience.
    - **2.** He proposed that induction was a form of reasoning characterized by a creative act of mind in which the reasoner "saw" relationships that went beyond what was "in" the data available to them.
    - **3.** Kepler, for example, did not simply find the elliptical nature of planetary orbits in Tycho's data; he "saw" that assuming an ellipse allowed the best explanation of the data that he could think of.
    - **4.** Fundamental ideas are induced in this way. They cannot be deduced from experimental data and are not merely generalizations. Some people "get" these ideas, always from experience, and they turn out to be explanatorily fertile, at least for a while.

  5. **5.** For Whewell, unlike Bacon, scientific reasoning was a creative process, not mechanical**.** Yet Whewell was not a Kantian, because he claimed that the fundamental ideas changed over time.

II. Whewell's theory of scientific knowledge was opposed by committed Empiricists, who argued that the objective truth of scientific knowledge derived from inescapable facts and logical reasoning.

- **A.** John Herschel was a more acute scientist and mathematician than his friend Whewell, and he responded very differently to the philosophical issues posed by justifying knowledge of nature.
  - **1.** Herschel rejected Whewell's idealism-tainted philosophy of science in favor of an updated version of Bacon's experimental method.
  - **2.** Herschel separated the process of scientific discovery from the process of justification of new knowledge claims, making the latter alone the object of an account of scientific knowledge.
  - **3.** By the careful use of experience to amend experience, Herschel argued that we could understand that scientific knowledge was about the world and how scientific knowledge accumulated, progressively.
- **B.** August Comte, like Bacon, contributed nothing to scientific knowledge but had a profound influence on 19th- and early-20th-century conceptions of knowledge and of a rational society.
  - **1.** Contemporary with Whewell, Comte formulated a developmental theory of mind in which the mind's maturity was reached when it reasoned based strictly on empirical facts and relationships among facts that have practical consequences.
  - **2.** He called this the "positive" stage of humanity and of human reasoning, having left metaphysics behind.
  - **3.** In principle, then, Comte's conception of scientific knowledge is a precursor of Pragmatism and its contingent, probable, and particular conception of knowledge. In fact, Comte repeatedly made the goal of science the discovery of necessary relationships among facts!
- **C.** John Stuart Mill was an active and influential figure in British social, political, and economic reform in the mid-19th century. His *System of Logic* offered an aggressively empirical theory of scientific knowledge.
  - **1.** Mill defended the traditional conception of induction against Whewell's reconceptualization of it. He argued that the mind adds nothing to facts when reasoning inductively but only extracts patterns from facts.
  - **2.** The object of inductive reasoning, then, is identifying the one correct pattern in a set of data; thus, the object of science is nature, not experience.
  - **3.** Using multiple cross-referenced experiments and inductive methods of data analysis, Mill argued that we could, as Newton said, identify the "true causes" of phenomena and not just construct logically consistent "stories" about data, à la Descartes.

III. Whewell's attribution of an active role for mind in reasoning was symptomatic of a trend in 19th-century philosophy, as was his claim that reasoning was intrinsically historical. Both claims would be of limited influence for 100 years, then erupt in the post–World War II period.

- **A.** The Enlightenment identification of reason as the only means by which personal and social well-being could be improved was repeatedly challenged, beginning with Rousseau, and on a broad front.
  - **1.** The Romantics rejected the hegemony of reason in human affairs. Some, such as William Blake, depicted it as leading humanity down a disastrous dead-end path. Others, such as the German poet Novalis, depicted the human condition as inevitably tragic, reason notwithstanding.
  - **2.** Søren Kierkegaard dismissed the rational approach to life—he called it the "ethical" stage—as incapable of guiding life decisions.
  - **3.** Friedrich Nietzsche argued that the traditional notion of reason was a myth because all reasoning was inevitably perspectival, proceeding from a particular location in cultural space-time.
  - **4.** Reason is, thus, inescapably expressive of a particular set of values, concepts, ideas, and judgments; it cannot provide a fulcrum for levering experience aside to look on reality.
- **B.** The attribution of an active role for mind was a continuing theme in the broader cultural context within which 19th- and 20th-century science continued to develop.

1. One form this theme took was the attribution of a role for the unconscious in shaping the content of consciousness and how we responded to that content.
2. Charles Sanders Peirce, the polymath founder of American Pragmatism, gave the name *abduction* to Whewell's idiosyncratic form of induction. He argued that our ideas are a response to problems that we become conscious of as posed by our experiences, and we accept as true those ideas that "solve" the problem.
3. Echoing Wilhelm Wundt and William James, John Dewey and the Gestalt school of psychology argued that perception and cognition were both selective and that the selection criteria came from the mind, not from the causes of experience.
4. The lines of thought represented by Fourier and Whewell call into question the objectivity, and the ultimate rationality, of scientific reasoning, theories, and knowledge claims.

Recommended Reading:

Friedrich Nietzsche, *The Will to Power.*

Richard R. Yeo, *Defining Science: William Whewell, Natural Knowledge and Public Debate in Victorian England.*

Questions to Consider:

1. What other responses to experience besides reason are we capable of? Is the superiority of reason over all other responses something we can know?
2. History is often enlightening, helping us to understand a situation or event, but historicity, the idea that all claims to truth/knowledge must be assessed relative to a particular cultural context, is threatening to many people. Why?

Lecture Twelve

Trading Reality for Experience

Scope: Fourier's theory of heat was published in 1822 and Herschel's defense of inductive science in 1830. Whewell countered that induction, as traditionally defined, could *not* play this role, while Mill countered Whewell by proposing an expanded logic of induction. Meanwhile, mathematics and mathematical physics were becoming increasingly abstract. Joseph-Louis Lagrange formulated what became a standard version of Newtonian mechanics whose equations described, not the motion of material particles in three-dimensional space and time, but the "motion" of properties of systems of material particles in a conceptual "space" of six or more dimensions. Thermodynamics, electromagnetic field theory, the kinetic theory of gases, and statistical mechanics described processes and patterns of relationships rather than things and their properties. The Darwin-Wallace theory of evolution was independent of the responsible biological mechanisms. In the last decades of the century, three physicists—Ernst Mach, Pierre Duhem, and Heinrich Hertz—argued from three different perspectives that theories were nonunique interpretations of experience, not descriptions of reality, and J. B. Stallo, a physics professor turned diplomat, exposed the metaphysical underpinnings of putatively empirical science.

Outline

I. Ironically, just when philosophers of nature adopted the name *scientist* to distance themselves from philosophy, they were forced to play philosopher!

  A. The diverse responses of scientists to the challenge of justifying scientists' claims to knowledge testified to their failure to meet that challenge.

    1. It is a fact that from 1600 to 2000, the overwhelming majority of natural scientists treated scientific theories as if they were descriptive of the way things "really" are "out there."

    2. There is a commonsense validity to this philosophically uncritical attitude that needs to be appreciated and respected.

    3. We are all "naive realists" in our daily lives, because naive realism is a successful strategy for daily living.

    4. But from Descartes on, the new scientists also recognized the problem posed by the Fallacy of Affirming the Consequent.

  B. Fourier's theory was symptomatic of what would become a trend in 19th-century science.

    1. Fourier showed that the claim to reveal reality was separate from providing a mathematics-based physical theory that worked.

    2. A separate criterion was necessary to justify the ontological claim of universal theories to be about reality, and there did not seem to be such a criterion.

    3. The challenge of linking theories to reality became more intense as physical theories became intensively mathematical.

  C. Herschel, Comte, Whewell, and Mill reflected the perceived need to identify what theories provided knowledge of and how. Developments within science intensified this perception.

    1. Michael Faraday's experiments revealed an intimate connection between electricity and magnetism, and he proposed the existence of electric and magnetic "lines" and "fields" of force to explain electric and magnetic phenomena.

    2. In 1856 and again in 1861, James Clerk Maxwell attempted to provide a mathematical theory of these fields in physical terms, employing the notion of "tubes" and "lines" of electric, magnetic, and electromagnetic force.

    3. In 1865 and 1873, however, Maxwell gave up physical models in favor of a purely mathematical description, à la Fourier.

II. William Thomson (Lord Kelvin) persisted in arguing that we did not understand any physical phenomenon unless we could provide a mechanical model of it, yet some of the most innovative theories of the century failed to provide such a model.

- **A.** Eminent scientists considered scientific theories explanatory if they "covered" the relevant phenomena and made correct predictions.
    - **1.** By the late 1860s, we saw, Maxwell had given up on a mechanical model of his electromagnetic field theory, even though its physical reality seemed assured by the startling predictions it made.
    - **2.** One of these predictions was that light was an electromagnetic phenomenon, i.e., electromagnetic waves of certain frequencies that travel at the same speed as all other electromagnetic waves.
    - **3.** A corollary prediction, confirmed in the 1880s by Oliver Lodge and Heinrich Hertz (of whom more below), was that all electromagnetic waves could, like light, be propagated in free space. (Guglielmo Marconi built the first radio technologies on this confirmation.)
    - **4.** The point here is that Maxwell's theory was one of a growing number that referred to entities that were in some sense real but were defined by the mathematical language of the theory itself.
- **B.** A still more radical segregation of physics and reality was proposed by the physicist Ernst Mach.
    - **1.** Especially in two major works, *The History of Mechanics* and *The Analysis of Sensations*, Mach developed a radically relational theory of what scientists know and how they know it.
    - **2.** Mach claimed that space, time, motion, mass, force, and energy were all names of relationships. Like Comte, and contra Newton, physics describes relationships. It does not reveal ultimate realities.
    - **3.** The objects of science are the phenomena of experience, and the objective of science is to invent the most compact summaries of experience, analogous to algebraic equations in relation to geometry.
    - **4.** Mach was, therefore, violently opposed to the reality of the atomic theory of matter, while completely accepting of atoms as explanatory devices in chemistry and physics.
- **C.** The French physicist Pierre Duhem followed a different path from Mach's to dissolving the uniqueness and finality of scientific knowledge.
    - **1.** In *The Aim and Structure of Physical Theory*, Duhem argued on logical grounds that experiments could neither decisively confirm nor decisively falsify a theory because theories are "under-determined" by data and complex enough to be adapted to any experimental outcome.
    - **2.** It follows that "crucial experiments," fundamental to logic-based theories of scientific knowledge, are impossible and that the response of scientists to experimental outcomes involves nonlogical acts of judgment.
    - **3.** Duhem's own rigorously mathematical-deductive methodology eschewed physical interpretations of his theories. He held that conceptual hypotheses were essentially transitory and, like Mach, that the business of science is descriptions of relations among phenomena, not identification of the external causes of experience (thereby leaving room for his Catholic beliefs).

III. It follows directly from the critiques of Mach and Duhem, and indirectly from the consequences of Fourier's move, that the truth of a theory is critically dependent on the assumptions on which it rests, and as the truth of these assumptions cannot be certain, scientific knowledge is necessarily conjectural, corrigible, contingent upon evolving experience and changing assumptions.

- **A.** The dependence of theories on their assumptions is nicely illustrated in a book entitled *The Principles of Mechanics* by the physicist Heinrich Hertz.
    - **1.** The book is quite technical, but the long introduction is really an essay concerning the philosophy of science.
    - **2.** Hertz explained that in this book he was going to develop a version of Newtonian mechanics explicitly based on a very strange assumption: that forces are caused by invisible masses.
    - **3.** He claimed that this bizarre version of mechanics was logically and empirically indistinguishable from the then dominant versions of mechanics.
    - **4.** It followed (in an echo of the implications of non-Euclidean geometry) that we cannot claim because the equations work, that the assumptions are correlated with what is truly "out there."
    - **5.** Scientific knowledge is thus irreducibly subjective to the extent that it is dependent on freely chosen assumptions!

B. Inescapably, one is led to wonder if the attribution to theories and their elements of correspondence to reality, as well as science's claims to objective truth and knowledge, are not aspects of the theorizing process itself.

  1. One must not dismiss the empirical fact that scientific knowledge, within science and among the general public, *is* supposed to reveal an underlying reality.
  2. The predictive successes of science make this seem inevitable, yet the history of science shows how problematic such claims are: they are continually changing over time!
  3. Consider the startling difference between what scientists claimed to know about nature in 1900, at what they thought comprised "reality," and what scientists today claim to know, claim that reality "is." Now imagine looking back at today from the vantage point of the year 2100.
  4. Almost contemporary with Hertz' book, *The Concepts and Methods of Modern Physics* by J.B. Stallo argued that modern science rested on metaphysical foundations, in spite of scientists' claims to have put philosophy behind them in favor of facts and logic.

Recommended Reading:

Jonathan Crary, *Techniques of the Observer.*

David Lindley, *Boltzmann's Atom.*

Questions to Consider:

1. How does the value of knowledge change when it is incomprehensible to all but a select few people?
2. Is there more value to knowledge than usefulness? If so, how do we assess that value?

Glossary

abduction: A name adapted by Charles Peirce from Aristotle's logic to refer to that moment in the reasoning process when a scientist "sees" that a problem can be solved by assuming that some idea (that is neither deducible from the data nor a simple generalization of the data) is true, hence part of the process of discovery rather than justification.

analysis: Especially in Descartes and Newton, reducing a phenomenon to the simple constituents of which it is composed and whose distinctive properties can explain the phenomenon when analysis is complemented by synthesis. Note well the assumption that phenomena are composed of discrete constituents with distinctive, fixed properties.

analytical philosophy: An early-20th-century development focusing attention on language, meaning, logic, and the relation between language and reality in formulating and solving philosophical problems. Bertrand Russell was one of its pioneers.

anomaly: In Thomas Kuhn's account of scientific theory replacement, anomalies are empirical findings that are inconsistent with a paradigm or theory.

axiomatic system: A fixed set of axioms, that is, sentences taken to be true, all of whose deductive logical consequences are then necessarily true, logically at least. If the axioms are statements about the world, then their logical consequences correspond to predictions about the world.

caloric theory: The theory, only abandoned in the mid-19th century, that heat is a weightless fluid.

Cartesianism: The school of thought that follows Descartes' strictly mechanical philosophy of nature and hypothetico-deductive method.

coherence theory of truth: The claim that a sentence about the world is true if it is logically consistent with the other statements about the world that we take to be true and consistent with the world as experienced (not as it is in itself).

contact forces: Direct mechanical contact as opposed to action at a distance.

correspondence theory of truth: The claim that a statement about the world is true if and only if it corresponds with the way the world is in itself, independent of the mind.

deconstruction: An alternative to analysis, holistic rather than discrete, as a method for understanding a phenomenon, literally or metaphorically construed as a text, by exposing the implicit and covert associations, relationships, and interactions that influence its meaning for us.

deduction: A form of reasoning/inference in which if the premises are true, the conclusion derived from them must be true.

Empiricism: The view that all of our ideas, and hence all of our knowledge, ultimately derive from sensory experience. The mind has innate capabilities but no innate content.

Enlightenment: A name given to the late-18th-century view that human beings had now reached a point in their development at which the application of reason alone, as in physical science and mathematics, could improve the human condition without limit.

epistemology: Theory of knowledge, from one of the Greek words for knowledge, *episteme*.

evolutionary epistemology: An objectivist theory of knowledge arguing that the evolutionary history of the human nervous system guarantees a correlation between our concepts and principles of reasoning with what is "out there."

falsificationism: Following Karl Popper, the view that an explanation, hypothesis, or theory must be falsifiable in order to be considered scientific, that a primary goal of experiment is to attempt to falsify rather than to confirm, and that falsification requires abandoning the falsified hypothesis, explanation, or theory.

Gestalt psychology: The school of psychology, founded in the early 20th century, that holds that the mind's own activity influences the mind's content and its interpretation, even with respect to sense perception (hence there is no passively received content in the mind that is simply "given" to the mind in experience).

hermeneutics: A Greek name for interpretation, contrasting the necessarily pluralistic character of interpretation with the, in principle, uniqueness of correct scientific explanations.

historicism: The view, first broadly supported at the turn of the 19th century, that all human activity, intellectual no less than political, social, and cultural, can only be understood and judged in its historical context.

idealism: The philosophical school that attributes a primary role to mind in the constitution of reality.

ideology: A term introduced by Condillac in the 18th century to refer to the study of ideas and their relationships, but especially after Karl Marx, referring to a consciously or unconsciously biased, hence false, response to experience.

induction: A form of reasoning in which even if the premises are all true, the conclusion is only probably true, never certain. Also, a form of reasoning that employs generalizations from particular experiences.

instrumentalism: A name for the view that knowledge, truth, and reality are attributes of what works to achieve desired ends, of what solves problems.

internal realism: The philosopher Hilary Putnam gave this name to a relational theory of scientific knowledge that was objective and meaningfully realist without requiring a correspondence theory of truth.

kinetic theory of gases: The theory that the physical properties of gases, temperature and pressure, can be explained statistically by treating gases as made up of vast numbers of rapidly moving, continually colliding atoms.

Logical Empiricism: A broader term than Logical Positivism, naming a realist and objectivist theory of knowledge in which truth, knowledge, and reality are correlated through the logical organization of direct, uninterpreted sense experience. Knowledge, and coordinately reality, is built up out of "atomic" units of meaning or events.

Logical Positivism: A version of Logical Empiricism associated especially with the response of a group of philosophers and scientists based in Vienna and Berlin to Ludwig Wittgenstein's 1920 *Tractatus Logico-Philosophicus*. By strictly separating theory statements from observation statements and demanding rigorous verification of all theory statements in terms of observation statements, they attempted to formulate a deductive realist theory of scientific knowledge.

materialism: The view that matter in motion is the only reality.

mechanical philosophy of nature: A materialistic determinism. Nature as a whole and every natural entity, living or not living, constitute a deterministic machine.

metaphysics: The study of the most fundamental features of reality and/or the most fundamental principles that make knowledge of reality possible.

modernism: The view that reason is both a necessary and a sufficient condition for achieving human well-being.

natural ontological attitude: Philosopher of science Arthur Fine's attempt at reconciling realism and antirealism by way of a modest, commonsense acceptance of the reality of the objects in abstract scientific theories conditional on the success of those theories.

naturalistic epistemology: Making physical scientific knowledge, its methods, and results the basis for a philosophical theory of knowledge.

neo-objectivism: A name I have given to attempts to defend the objectivity of scientific knowledge in the wake of the critiques of it by Fleck, Hanson, Kuhn, and the social construction theorists.

Newtonianism: The view that through experiment, the mathematical laws describing the forces acting causally among material particles—and between material particles and immaterial agencies such as light, electricity, magnetism, and selective chemical attraction—can be discovered.

nihilism: Nothing matters: the rejection of all value judgments as subjective and arbitrary.

non-Euclidean geometry: Deductively sound geometries that, by replacing one (unprovable) axiom of Euclidean geometry with an equally plausible (unprovable) axiom, reach conclusions incompatible with those in Euclidean geometry. The inescapable consequence is that logical necessity has no necessary connection with reality.

normal science: In Thomas Kuhn's scheme, the form of "puzzle-solving" characteristic of scientific practice within the bounds of an accepted paradigm. Thus, the puzzles are suggested by the paradigm as contributing to completing/extending it, and it is expected that solutions exist.

objectivism: The view that the validity of scientific knowledge is independent of the conventions and practices of the community of scientists.

ontology: The study of the ultimately real.

Operationalism: Percy Bridgman's theory of scientific knowledge, according to which the meanings of scientific concepts, such as space, time, mass, and electron, *are* the experimental procedures/operations used to measure them.

paradigm: A term made prominent (notorious?) by Thomas Kuhn to refer to the acceptance by the community of scientists working in an area of a common conceptual framework, methodological criteria, and ontology, e.g., Mendelian genetics, quantum theory, Big Bang cosmology, and plate tectonic theory, among others.

Phenomenalism: Ernst Mach's theory that the objects of scientific knowledge are the phenomena of sense experience, not an independently existing reality. Concepts and theories are useful and fertile ways of summarizing empirical experience; they give us no knowledge of what is "out there."

positivism: The philosophy that knowledge can only be based on the organization of empirically given facts, which are the ultimate criteria of truth/falsehood.

postmodernism: The claim that modernism was a dogma, and the glorification of reason an ideology—a weapon used to advance the interests of the bourgeoisie and the intellectual elites supported by them.

Pragmatism: An American philosophy, introduced by Charles Sanders Peirce in the 1870s, but developed along different lines in the early 20th century by John Dewey and others. Pragmatism makes action, contingency, and valuing central to knowledge, rejecting universality, necessity and certainty, traditional metaphysics, and the polarization of experience into mind versus world.

Rationalism: The philosophy that the human mind is capable of achieving universal, necessary, and certain knowledge of the real, analogous to the knowledge it has achieved in mathematics.

realism: As applied to science, the view that scientific theories describe what is *really* "out there," independent of our experience and causing that experience.

reductionism: The view that physics is the foundational science and that all other sciences reduce to physics in principle, though in practice it may be more effective to treat chemical, biological, psychological, and sociological entities and causal agencies as if they were elementary.

relativism: The view that all value judgments are relative to some cultural context, at best intersubjective but not truly objective, that is the source of value criteria. There are no universal principles or criteria of value.

representational theory of knowledge: The theory, as in John Locke, that there exists a representation of the external world inside the mind, as if somewhere in the mind there is a "mirror" in which the external world is reflected, and that knowledge is a correct description of this representation.

rhetoric: The art (or science, to its classical practitioners) of persuasive argument, especially oral argument.

skepticism: A family of philosophies, ranging from destructive to constructive, that share the view that there is no such a thing as universal, necessary, and certain knowledge of the world. David Hume, following the Roman philosopher Cicero, was a constructive, or "moderate," skeptic.

Sophists: Greek philosophers, among them Protagoras, Gorgias, and Isocrates, active from the mid-5th century B.C.E. through the 4th century B.C.E., who shared an action-centered conception of philosophy and reason, contingent and probabilist conceptions of knowledge and truth, and relativist concept of values. For Plato and Aristotle, they were the enemy.

structuralism: Initially an anthropological theory promoted by Claude Levi-Strauss to explain myths and cultural institutions, structuralism took the intelligentsia of the 1960s and 1970s by storm, interpreting all meanings and values as expressions of structure.

symbolic logic: A 19th-century development, the introduction of symbolic notation revolutionized logic the way that the 16th-century introduction of mathematical notation revolutionized mathematics. By the end of the century, the millennial subordination of relationships to substances had been overturned and the discipline of mathematical logic was born.

synthesis: In scientific methodology, especially for Newton, synthesis is the complement of analysis: reconstructing the phenomenon to be explained after its analysis into elementary constituents with fixed properties.

taxonomy: Classification: Are there, as Plato held, natural schemes of classification for natural phenomena, or are all classification schemes conventional and, thus, a reflection of human interests?

theism: Acknowledgement of God as the creator-source of the Universe but denying God an ongoing role in the Universe or human affairs.

thermodynamics: A new science of heat created in the mid-19th century around the recognition of energy as an elementary feature of reality, on a par with matter.

thought collective: In Ludwik Fleck's terminology, a community of thinkers with similar education and training, related research programs and objectives, and shared criteria for identifying problems and evaluating proposed solutions to those problems.

thought style: In Fleck, a very close analogue to Kuhn's term *paradigm*.

Biographical Notes

Aristotle (384–322 B.C.E.). To his medieval Christian, Islamic, and Jewish disciples, Aristotle was simply "the Master of them that know."

Bacon, Francis (1561–1626). Bacon rose to the position of Lord Chancellor (roughly analogous to the position of Chief Justice of the U.S. Supreme Court) under King James but was convicted of taking bribes and dismissed in disgrace. He championed educational reform for the masses to create a technologically knowledgeable public as the means to make England wealthy and powerful through continuous innovation.

Berkeley, George (1685–1753). Berkeley was a bishop in the Anglican Church, serving an Irish diocese. He was born in Ireland to English parents but identified with Ireland, not England. With Locke and Hume, Berkeley is counted one of the three founding British Empiricists.

Bohr, Niels (1885–1962). As a young Danish Ph.D., Bohr won a fellowship to work in the Cambridge laboratory of J. J. Thomson, discoverer of the electron. Because neither liked the other much, Bohr left Cambridge for Manchester and the much livelier laboratory of Ernest Rutherford, who had just published his Solar System model of the atom. It was to rescue that theory that Bohr proposed the bizarre rules for a quantum theory of electrons that, by 1925, evolved into quantum mechanics.

Boltzmann, Ludwig (1844–1906). An Austrian physicist, Boltzmann made important contributions to thermodynamics, the kinetic theory of gases, and electromagnetic theory by employing probability theory and assuming the atomic constitution of matter. This led to the creation of the field of physics called statistical mechanics, developed further by J. Willard Gibbs.

Boyle, Robert (1627–1691). A British aristocrat, Boyle was deeply religious, as well as a pioneer experimental philosopher and founding member of the Royal Society.

Brahe, Tycho (1546–1601). Brahe was a Danish astronomer whose fortune was sealed when his father, gallantly but foolishly, drowned trying to save the Danish king from drowning. A grateful king gave Brahe the support Brahe needed to become the best pre-telescopic observational astronomer of all time. When Brahe died, Kepler snatched his data and used them to propose a version of Copernicus's theory that was ultimately vindicated by Newton.

Bridgman, Percy (1882–1961). An American experimental physicist who won the Nobel Prize for his research on the effects of high temperature and pressure on the properties of materials. Bridgman worked on his own—only two of his hundreds of publications have a co-author—at a time when collaboration was becoming increasingly common.

Campbell, Donald (1916–1996). An eminent American social psychologist, famed especially for his innovative studies of research methodologies.

Cicero, Marcus Tullius (106–43 B.C.E.). A Roman senator and consul, wealthy and powerful, whose political activism turned catastrophic for him and his family. His works were published to great acclaim among the Humanists during the Renaissance. His dialogue *Academica* is a debate over whether Plato's Academy had been ruined or restored after its takeover by philosophers who rejected Plato's conceptions of rationality and of knowledge as universal, necessary, and certain.

Collins, Harry (n.d.). A British founder of the sociology of science, influenced early in his career by Jerome Ravetz, now at Reading University.

Comte, Auguste (1798–1857). Although in some sense preceded by Montesquieu, Turgot, and his own mentor/employer Saint-Simon, Comte is often considered the founding "father" of sociology, as well as a fact-based anti-metaphysical philosophy of Positivism that evolved into Logical Empiricism/Logical Positivism and influenced American Pragmatism and British analytical philosophy.

Condorcet, Marquis de (1743–1794). A French mathematician, he became a collaborator with his mentor, Turgot, in the application of probability theory and statistics to decision-making under uncertainty and public policy.

Actively involved in the French Revolution, he opposed Robespierre's takeover of the Convention, and during three years of living in hiding, he composed an essay foreseeing the inevitable progress of humankind toward security, prosperity, and the rational conduct of human affairs.

Copernicus, Nicolaus (1473–1543). A Polish priest, Copernicus spent years in Renaissance Italy studying philosophy, especially ancient Greek philosophers newly translated into Latin, including Plato. In 1512, he published a brief account of a Sun-centered theory of the heavens, the idea for which he said he got from reading that Aristarchus of Samos had proposed such a theory 1,700 years before. Copernicus's masterwork, *On the Revolution of the Heavenly Spheres*, was published in the year that he died, having been seen through the press by a Lutheran minister admirer, Andreas Osiander.

D'Alembert, Jean (1717–1783). A Paris church foundling, d'Alembert became one of the leading French mathematicians of the late 18th century, making important contributions to mathematical physics and celestial mechanics. Diderot talked him into participating in the *Encyclopédie* project, and he contributed an introductory essay on the access that modern science provides to knowledge, truth, and reality.

Dalton, John (1766–1844). Dalton was born into a small-town British Quaker family and was self-taught in science. He studied meteorology intensively and adopted the atomic theory of matter to explain the mixing of gases in the atmosphere. His atom was solid, with no internal parts.

Darwin, Charles (1809–1882). Darwin's scientific career, genius, and reputation derive from the impact of his five-year global voyage as naturalist on H.M.S. *Beagle*, a Royal Navy ship on a military mapping mission. It was, however, a fluke that he was sent on that mission, having no credentials whatsoever at the time as a new Cambridge graduate of no special distinction. The "pull" of his Cambridge botany professor (and the lack of interest from anyone else!) was responsible for his appointment, along with Darwin's eagerness to avoid the career in the Anglican Church that his wealthy physician father envisaged for him!

Derrida, Jacques (1930–2004). Derrida was born and raised in Algiers; after World War II, he moved to France and rose to a professorship, initially at a provincial university but eventually in Paris. His breakthrough book, *On Grammatology*, is a bold extension of the Swiss linguist Ferdinand de Saussure's theory of language as a closed system of relations/differences among arbitrary signs. One type of these relations is open-ended associations with other signs that generate dynamic networks of meanings, precluding a single "correct" reading of any text. Derrida's deconstructionist methodology swept Europe and the United States like a computer virus in the 1970s but then suffered a backlash in the 1990s that was as excessive as its earlier embrace.

Descartes, René (1596–1640). Though French and a loyal Catholic, Descartes lived his adult life in Protestant Holland, which at the time had the most liberal "toleration" climate in Europe. He maintained close ties with a wide range of intellectuals and institutions by way of Marin Mersenne, a French priest who served as a kind of living "switchboard" connecting intellectuals in a dozen countries with him and with one another.

Dewey, John (1859–1952). Dewey took the initial formulation of Pragmatism by Charles S. Peirce and William James's interpretation of those ideas to the level of a comprehensive, systematic philosophy. It was natural for that philosophy to be applied to practical social problems, and Dewey devoted much effort to doing just that, especially in the areas of education and social reform.

Diderot, Denis (1713–1784). Diderot was a philosopher, novelist, playwright, all-purpose intellectual, and social reformer, in addition to bringing his vision of the *Encyclopédie*—spreading scientific and, especially, commercialized technological knowledge to the masses—to reality as its editor-in-chief. He maintained that vision through the decades required for the project's completion and the repeated political persecution to which he and other key contributors were subjected.

Duhem, Pierre (1861–1916). An eminent late-19th-century French physicist, Duhem's conventionalist theory of scientific knowledge and truth were motivated at least in part by his Catholic religious beliefs. That is, a conventionalist theory of truth leaves room for other claims to truth, for example, religious and aesthetic claims. In parallel with his career in physics, Duhem also was a founder of modern scholarly history of science, especially the history of science in the High Middle Ages (1100–1400).

Einstein, Albert (1879–1955). It is surely significant somehow that until his "miracle year" of 1905, Einstein did not display any hint of what he was to accomplish and become, creating relativity theory and playing a central role in the creation of quantum theory. Einstein's notorious stubbornness in rejecting the finality of quantum mechanics as a theory of nature may yet be vindicated as sound intuition by the fact that physicists have been unable to reconcile relativity theory with quantum theory after more than half a century of trying. Adulation of Einstein for his intellect, his professional generosity, and his social and political views tends to overlook the complexity of his personal life as husband, father, and lover.

Faraday, Michael (1791–1867). Like Alfred Russell Wallace, among others, Faraday rose from a working-class background via self-education to a place among the most eminent scientific thinkers of the 19th century. Faraday's lack of formal higher education and, perhaps, his own lack of aptitude translated into weak mathematical skills, so that his interpretations of his ingenious experimental discoveries were largely qualitative. Faraday's discovery of the dynamo principle (1821–1831) still underlies virtually all electricity generation today (photovoltaic cells are one exception), and he was an important pioneer of organic chemistry and electrochemistry.

Feyerabend, Paul K. (1924–1994). Feyerabend was born in Vienna, was especially attracted to the study of theater and music in college, was drafted into a German work battalion during the war, then volunteered for the army and officer training. He was awarded an Iron Cross for combat heroism on the Russian Front and was injured during the retreat, a bullet nicking his spine. He walked with a cane for the rest of his life. After the war, he was attracted first to physics, then to philosophy, initially at the University of Vienna, then at the London School of Economics, where Karl Popper taught. He became increasingly critical, not just of Empiricist philosophies of scientific knowledge but of the traditional philosophical conception of rationality and the way that our personal, social, and political responses to experience are shaped by ideological conceptions of rationality.

Fleck, Ludwik (1896–1961). Fleck was a Polish Jew and a leading immunologist. With the Nazi occupation of Poland in 1939, Fleck's situation teetered on catastrophe, but the Nazis offered him a deal. If he would work on "vaccines" against infectious diseases to which their troops were exposed in the Eastern Front, he and his family would be allowed to live. After the war, Fleck won academic recognition in Poland for his prewar scientific achievements but followed his family in emigrating to Israel, where ironically he did not receive an academic appointment!

Foucault, Michel (1926–1984). Foucault was born in Poitiers, France, and from an early age, became deeply committed to left-wing political causes challenging the social power establishment, in parallel with his development of a historicist challenge to the intellectual power establishment. His historical studies of sexuality, madness, and the prison system in Western culture embody his "archaeological" method, exposing the evolving rules that validate claims to truth, objectivity, factuality, and rationality.

Fourier, Joseph (1768–1830). Fourier, born and raised in the French city of Auxerre, narrowly escaped execution during the Terror phase of the French Revolution and went on to lecture at the newly created École Polytechnique, then the finest science- and mathematics-based engineering school in the world. Fourier's personal and professional life were affected by his deep political entanglements, especially achieving rewards and promotions under Napoleon's government but then having to make himself acceptable in 1815 to the restored Bourbon monarchy, a trick he managed to pull off neatly.

Galilei, Galileo (1564–1642). As with Einstein, adulation of Galileo and sympathy by modern intellectuals for his position in his conflict with the Church have obscured the complexity of that conflict and the legitimate concerns of the Church. Galileo was born in Pisa and parlayed his construction of a telescope and its astronomical application into the most prestigious and highly paid academic position in Italy. He had three children by a mistress he abandoned upon moving from provincial Pisa to the elegant court of the Medici in Florence.

Gamow, George (1904–1968). Gamow, a fertile theorist never accorded the respect he deserved as one of the most important physicists of the mid-century, was born in Odessa and received his Ph.D. in physics from the University of Leningrad. He worked at Niels Bohr's institute in Copenhagen and with Ernest Rutherford at Cambridge, making important contributions to the theory of transmuting elements and deducing from quantum theory the bizarre and very important phenomenon known as quantum tunneling. After World War II, Gamow and his collaborators developed what became known as the Big Bang theory of the origin of the Universe. Shortly after Watson and Crick announced the structure of DNA, Gamow wrote to Crick suggesting that the sequence of four bases that make up the DNA helices constituted a code for assembling the 20 kinds of amino acids into proteins.

Gibbs, J. Willard (1839–1903). An American physicist whose entire career was spent at Yale—in 1863, he received the first engineering Ph.D. Yale awarded—and who, except for three years in Europe, rarely left New Haven. Gibbs was recognized as a world-class physicist, one of a handful of Americans in that category in his generation. His lasting contributions were to the application of thermodynamics to chemical reactions and as one of the creators of statistical mechanics (see **Boltzmann**).

Gold, Thomas (1920–2004). Austrian-born physicist who became an American citizen and spent his career at Cornell University. Gold was highly respected for his knowledge of physics, but his maverick theories were typically dismissed, in spite of some surprising confirmations of them.

Goodman, Nelson (1906–1998). An American philosopher who spent 11 years after graduating from college running a Boston art gallery before completing a Ph.D. His book *Fact, Fiction and Forecast* strengthened David Hume's criticism of induction as the basis for knowledge of nature, while *Ways of Worldmaking* argued that science was only one of a number of languages for describing experience, no one of which could claim unique truth. Goodman was a professor of philosophy at the University of Pennsylvania for 18 years and wrote on aesthetics, as well as issues in philosophy of science and the logic of probability.

Gorgias (c. 483–378 B.C.E.). With Protagoras, one of the greatest of the Sophists, who were contemporaries of Socrates. Both Gorgias and Protagoras developed "tragic" conceptions of man, in which reason was ultimately unable to overcome the gulf between experience and reality, though irrational means were available to achieve this partially and contingently.

Hanson, Norwood Russell (1922–1967). Hanson was an American philosopher of science at Yale University. His book *Patterns of Discovery* (1958), influenced by the ideas of Ludwig Wittgenstein after he had turned against Logical Empiricism, posed a serious challenge to the separation of observation and theorizing that was essential to Logical Positivist and, more generally, to objective Empiricist accounts of scientific knowledge. Hanson argued that seeing inevitably incorporated idea- and knowledge-based expectations, a view that was echoed in the later social construction theory of science, for example, in the case studies of scientific practice of Harry Collins, Bruno Latour, and Andrew Pickering. Hanson also insisted on an understanding of the distinctive logic of discovery (which Popper had dismissed as illogical) as essential to an understanding of the status of scientific knowledge claims, a view central to Thomas Kuhn's theory of science.

Harvey, William (1578–1657). A British physician and active experimentalist, Harvey studied anatomy at the University of Padua, where Vesalius had revolutionized the study of anatomy with his careful dissections and where his students maintained an outstanding research tradition for generations. Harvey formulated the first empirically supported theory of the circulation of the blood throughout the body. The "missing link" was the actual transfer from the finest arteries to the finest veins and that had to wait until Malpighi revealed the tiny capillaries that bridge the arterial and venous systems.

Heisenberg, Werner (1901–1976). Heisenberg was born in Duisberg, Germany, and received his Ph.D. in theoretical physics at the University of Munich at the age of 22 under Arnold Sommerfeld, perhaps the first senior physicist to embrace Bohr's quantum theory of the atom. Heisenberg was 25 when he proposed what Max Born named quantum mechanics as a systematic solution to the problems that had accumulated in quantum theory between 1913 and 1922. He discovered that his solution predicted the Uncertainty Relations, and in the course of reflecting on their significance, he and Bohr developed a probabilistic interpretation of quantum physics. Appointed by Hitler to head Germany's atomic bomb effort, Heisenberg seems to have made a calculating error that led to a gross overestimation of the size of an atomic bomb, such that it could not be carried by any foreseeable aircraft.

Hempel, Carl (1905–1997). Hempel was born in Germany and, as an undergraduate and graduate student, studied mathematics, mathematical logic, physics, and philosophy of science with some of the greatest thinkers of the age, among them: David Hilbert, Hans Reichenbach, Max Planck, John von Neumann, and Rudolf Carnap. Hempel and Paul Oppenheim collaborated on a large number of papers that evolved into Hempel's Hypothetico-Deductive theory of scientific explanation.

Herschel, John (1792–1871). Herschel was the son of the famous German-born English astronomer William Herschel, who discovered Uranus and who, working with his spinster sister, Caroline, made many other major astronomical discoveries using huge open-tube telescopes of his own design. John was also an astronomer and a highly gifted mathematician, educated at Cambridge, where he became friends with Charles Babbage and led a revolt against British math education, still based on Newton's calculus notation. He spent four years in Cape Town, South Africa, observing Southern Hemisphere stars and "nebulae" (many of them later determined to be galaxies), including the Large and Small Magellanic Clouds (mini-galaxies gravitationally bound to the Milky Way). He played an important behind-the-scenes role in improving early photography technology through his friendship with Fox Talbot.

Hertz, Heinrich (1857–1894). Hertz was a German physicist who left a legacy out of all proportion to his short life. He died of blood poisoning, possibly from the effects of an untreated tooth infection that first manifested itself in 1887 and migrated into his jaw bone. Hertz's *Principles of Mechanics*, whose introduction contains his "conversion" to the view that scientific theories are not uniquely true pictures of reality, was published posthumously.

Hesse, Mary (1923–). Mary Hesse is a British philosopher of science who emerged in the 1960s as an exceptionally articulate defender of an anti-realist conception of scientific truth. Like Pierre Duhem, whose argument for the underdetermination of theories by empirical data she defended, Hesse wanted to protect a place for religious truth complementary to scientific truth, so the latter could not be unique. Her approach to scientific truth is as a language, similar to Goodman's approach. She was a very early proponent of the view that the philosophy of science needed to be approached through its history (as with Kuhn, among others, later), and her own theory of scientific knowledge interprets scientific theories as employing models, analogies, and metaphors (as with Ron Giere and Philip Kitcher). The mature expression of her views is in *Revolution and Reconstruction in the Philosophy of Science*, advancing the ideas in her earlier books, including *Forces and Fields.*

Hobbes, Thomas (1588–1679). Hobbes was a political philosopher whose book *Leviathan*, interpreting the natural state of man as a war of all against all, justified the centralization of all power in society in the hands of a monarch whose charge was to keep the peace. Hobbes was a materialist for whom mind was also a material phenomenon, and he proposed that reasoning was a species of calculation. He defended a deductive, universal, necessary, and certain conception of knowledge and had an unreasonable estimation of his skills as a mathematician.

Hooke, Robert (1635–1703). Hooke was born on the Isle of Wight and showed great mechanical ingenuity as a child, building the toys he played with. He was a multifaceted scientist even by the standards of the age. His *Micrographia* (1665) revealed extraordinary skill in using the microscope, and he worked as a consultant to instrument makers who sold microscopes and telescopes to wealthy customers who needed assistance setting up, using, and maintaining those finicky early instruments. He invented, independently of Huyghens, the first watch movement driven by the unwinding of a particular kind of tightly wound spiral spring; speculated that air was not an element but had a part to it responsible for life; and was appointed, along with Christopher Wren, the task of planning the rebuilding of London after the catastrophic fire of 1665. Unlike Newton, Hooke was an extremely social man, outgoing, voluble, a habitué of the new coffee houses, fond of women, and argumentative.

Hoyle, Fred (1915–1998). Hoyle was an English physicist who rejected the idea of a beginning to the Universe and coined the name "Big Bang" to deride Gamow's late-1940s theory of the origin of the Universe. His own Steady State theory required that complex atoms be synthesized out of hydrogen atoms continually created out of the quantum vacuum.

Hubble, Edwin Powell (1889–1953). One of the greatest of American astronomers, Hubble "owned" the 100-inch Mt. Wilson telescope. He used that telescope to establish that there were other galaxies than the Milky Way and that the Universe was expanding—estimating a size for the Universe as a whole of about 4 billion light years.

Hume, David (1711–1776). Born in Edinburgh, Hume was one of a group of extraordinarily influential Scottish figures in the 18th century, among them the "common sense" philosopher Thomas Reid, the economist Adam Smith (whose *The Wealth of Nations* was published the year Hume died), and the instrument maker James Watt, whose improved steam engine triggered the Industrial Revolution. Hume was prudent enough to have his *Dialogues Concerning Natural Religion*, with its critique of Christianity, published posthumously.

Huyghens, Christian (1629–1695). A Dutch mathematician and mathematical physicist; father, Constantine, was a famous epic poet and friend of Descartes, who often visited their house when Christian was young. Huyghens was the first to demonstrate that curved motion was forced motion, opening the way to modern mechanics. He went out of his way on a trip to England to visit Newton but was coldly received. He proposed relational definitions of space (and, possibly, of time) and of motion, in contrast to Newton's absolute definitions, and formulated a wave theory of light against Newton's particle theory. He invented a form of pendulum clock that kept accurate time even when moved and became embroiled in an ugly controversy with Robert Hooke over their respective claims to have invented the spring-wound watch movement.

James, William (1842–1910). A Bostonian, James introduced the study of experimental psychology to America, and his *Principles of Psychology* (1890) was both a serious text and a popular success. He introduced the term *stream of consciousness* and developed ideas, influenced by the German experimental psychologist Wilhelm Wundt, that would later become incorporated into Gestalt psychology and still later into cognitive psychology. From his youth, he was close with Oliver Wendell Holmes, Jr. and Charles S. Peirce and was responsible for publicizing the latter's creation of Pragmatism. His brother was the novelist Henry James.

Kant, Immanuel (1724–1804). Kant was born and died in Konigsberg, then a city in Prussia, and seems never to have traveled further than its near suburbs. His essay "What Is Enlightenment?" is a manifesto for philosophical rationality and modern science as the means to perfecting human well-being. He applied his theory of knowledge to ethics in his *Critique of Practical Reason* and to aesthetics and purposiveness in nature in his *Critique of Judgment*.

Kepler, Johannes (1571–1630). A German astronomer, born near Stuttgart and educated at Tubingen University in astronomy and mathematics, Kepler became an early adherent of the Copernican system, which was taught by his astronomy professor Michael Maestlin as a mathematical scheme, not physically real. After several years studying theology with a view to becoming a Lutheran minister, Kepler committed to astronomy and laid the foundations of the modern physical theory of the Solar System, though this was not appreciated until Newton. The Copernican Revolution in astronomy might more accurately be called the Keplerian Revolution. A casual fantasy he wrote about flying to the moon almost got his mother executed as a witch!

Kitcher, Philip (1947–). An American philosopher of science of distinction currently at Columbia University in New York City. Kitcher has written on philosophy of physics, sociobiology, philosophy of mathematics, artificial intelligence, and science policy, all in a deeply thoughtful, carefully considered, and clearly articulated way

Kuhn, Thomas (1922–1996). Kuhn was trained in physics and the history of physics and seemed to be the last person likely to write a book that would undermine the traditional conception of scientific knowledge as objective, realist, and progressive. He was commissioned to write what emerged as *The Structure of Scientific Revolutions* by members of the Logical Positivist school of thought, who certainly didn't expect what emerged, and neither did Kuhn. He exerted considerable effort for the rest of his life distancing himself from the relativist, postmodern theories of scientific knowledge that drew support from *Structure*.

Latour, Bruno (1947–). A French sociologist, Latour is one of the most aggressive champions of the socially constructed character of scientific knowledge. He adopted an actor-network theory of how a community constructs both what it produces and the criteria for justifying and legitimating what it produces. He is a prolific writer and convincing speaker who has a gift for exposing critical vulnerabilities in the practice of science that call into question claims that scientific knowledge is about what nature is.

Leavitt, Henrietta (1868–1921). An American astronomer, one of a group of late-19th- and early-20th-century female astronomers and scientists who were underemployed and underappreciated because of social prejudices. Between 1908 and 1912, she developed and published her observations of a relationship between the period of a variable star and its magnitude, which created the first cosmic yardstick, a means of estimating the distance of variable stars and, later, of galaxies within which variable stars could be observed.

Leibniz, Gottfried Wilhelm von (1646–1716). A German philosopher, mathematician, logician, and physicist, Leibniz developed a relationship-based metaphysical system that dominated German philosophy until Kant and became influential again in the 20th century. Through manuscripts of Leibniz's brought to light by Bertrand Russell, Leibniz was recognized as having anticipated the branch of modern mathematics called topology, as well as modern symbolic logic. He expended a great deal of effort attempting to reconcile Protestantism and Catholicism, obviously to no avail.

Locke, John (1632–1704). Locke had a B.A. and M.A. from Christ Church College at Oxford University and, for almost 20 years, was a close friend of and physician to the earl of Shaftesbury. Both men fled to Holland in 1681 because of the Parliamentary crisis in England, resolved in 1688 with the deposition of James II. Locke returned to England with William of Orange's accession to the throne, having been a political advisor to William in Holland. In 1690, Locke published two books of lasting influence: the *Essays Concerning Human Understanding* and *Two Treatises of Government*, which apart from its influence on British political reform in the 18th century, was a major influence on the U.S. Constitution.

Mach, Ernst (1838–1916). Mach was born in what now is the Czech Republic. He was educated at the University of Vienna and was, for 28 years, a professor of physics at Prague University, but his research specialty, psychophysics, reflected his experiences at Vienna, where he encountered Gustav Fechner's pioneering research into the physics of perception. His defense of relational definitions of mass, as well as space, time, and motion, influenced Einstein, at least indirectly.

Mannheim, Karl (1893–1947). In spite of his German-sounding name, Mannheim was Hungarian, born and educated in Budapest. He taught at the University of Frankfurt until dismissed by the Nazis in 1933, then at the London School of Economics. He can be seen as a precursor of Foucault (for example, in *The Order of Things* and in *The Archaeology of Knowledge*) in arguing that all knowledge "structures" bear the influence of the social context in which they are formulated. Although Mannheim was influenced by the writings of Karl Marx, he was seen as a rival by the contemporary Marxist Frankfurt School of sociologists because his theory implied that Marxism, too, was an ideology rather than "the" truth.

Maxwell, James Clerk (1831–1879). Newton, Einstein, and the Scotsman Maxwell are often listed as the giants of modern science. Maxwell's field theory of electromagnetic energy immensely enriched the prevailing materialistic conception of nature and made relationships as central to scientific accounts of reality as things were. This theory was directly responsible for the invention of radio, while Maxwell's contributions to the kinetic theory of gases introduced statistical processes into nature, and his statistical interpretation of the laws of thermodynamics supported the reality of atoms.

Mill, John Stuart (1806–1873). As a child, Mill's father, James, was determined that his son be a prodigy, and he was "force-fed" education accordingly. Mill rose to the challenge but, as a young man, suffered a breakdown that influenced the subsequent course of his life. In addition to his *System of Logic*, a defense of his conception of "simple" induction as the only sound foundation for scientific reasoning, Mill was a champion of Jeremy Bentham's utilitarian philosophy (as amended by Mill) and of liberal social and political reform, especially women's rights and freedom of speech.

Montesquieu, Charles Louis (1689–1755). A French social and political philosopher, Montesquieu's political activism and ridicule of French institutions in *The Persian Letters*—an account of French life through the eyes of a visitor from Persia—led him to spend some time in England. There, he was startled to discover a better fed, better educated, happier public; greater freedom of thought and speech; and John Locke. Montesquieu returned to France and wrote his *Spirit of the Laws*, which in its section on the republican form of government, served as another conduit for Locke's ideas to the founders of the American Republic.

Newton, Isaac (1642–1727). If Aristotle was "the Master of them that know" to medieval and Renaissance philosophers, Newton was that to 18th- and 19th-century scientists. He was also quite eccentric and extremely temperamental. He took religion very seriously, resigning his cushy fellowship at Trinity College of Cambridge University rather than sign an oath that he believed in the Trinity (he was a Unitarian). He wrote at great length on biblical chronology, using his astronomical theories to date biblical events, and believed he had decoded the mathematical secrets that God had encoded in the proportions of the Israelite Tabernacle and the Solomonic and post-Babylonian Exile Temples in Jerusalem.

Nietzsche, Friedrich (1844–1900). Nietzsche was German but expressed strongly negative views of Germans and the newly unified Germany in his writings. At the age of 25, he was appointed to a professorship in classical philology at the University of Basel in Switzerland but resigned after 10 years, in part because of ill health but largely because of a philosophical vision that he needed to pursue. In the next 10 years, he wrote prolifically and brilliantly, adopting an aphoristic style, declamatory rather than argumentative, that mirrored his criticism of traditional philosophical conceptions of rationality and knowledge. Then, he went mad and, 10 years later, died. His vision is best expressed in *The Birth of Tragedy*, *The Genealogy of Morals*, *Beyond Good and Evil*, and the posthumous *The Will to Power*.

Novalis/Friedrich Leopold von Hardenberg (1772–1801). Novalis was an early Romantic poet and highly influential in spite of dying at 29 and leaving a small body of work, notably his *Hymns to the Night*. His icon was a blue flower, symbolizing the ultimate unattainability of what one longs for most.

Parmenides (5th century B.C.E.). Very little is known about Parmenides except from fragments of his works cited by others, his student Zeno, and a Platonic dialogue of that name. Parmenides used rigorous logical reasoning to defend absolute conceptions of truth, knowledge, and reality, and these become ideals for Plato's Socrates, though in forms Parmenides almost certainly would have rejected.

Peirce, Charles Sanders (1839–1914). Peirce, as self-destructive as he was brilliant, made innovative contributions to geophysics, mathematics, logic, theory of signs (semiotics), and philosophy. He was one of a handful of European-class American scientists/intellectuals in the second half of the 19th century but, because of personal behavior, never received an academic appointment, lost the government position with the U.S. Geological Survey that his well-connected mathematician father had obtained for him, and squandered the money raised for him by well-meaning friends, such as William James.

Pickering, Andrew (c. 1948–). British by birth, Pickering emigrated to America and the University of Illinois after the publication of his masterly *Constructing Quarks*. A subsequent book*, The Mangle of Practice*, attempted to formulate a role for nature as constraining scientific reasoning without betraying social construction theory.

Planck, Max (1858–1947). Planck, born in Kiel, Germany, and educated at the Universities of Munich and Berlin, started quantum theory in December 1900 with a tentative hypothesis that he spent the next decade trying to replace! He became a major figure in German physics and was a deeply patriotic German, opposed to Hitler's policies and one of the few who stood up to them, resigning his presidency of the Kaiser Wilhelm (research) Institute in protest of the dismissal of Jewish scientists. He lost his last surviving son, a senior officer in the German army, to the Gestapo when, on Hitler's direct order, he was tortured and gruesomely murdered, along with all others involved in a bungled 1944 attempt to assassinate Hitler.

Plato (428–348 B.C.E.). Alfred North Whitehead said, "All of Western philosophy is a footnote to Plato." Martin Heidegger, next to Wittgenstein perhaps the second most influential philosopher of the 20th century (but neck and neck with Derrida as the most opaque), inadvertently seconded this assessment in arguing that Plato single-handedly put Western philosophy on a dead-end path that it had been following ever since!

Poincaré, Henri (1854–1912). A giant of early-20th-century "pure" as well as applied mathematics, Poincaré was also a great stylist as a writer about science and its philosophy, achieving the extraordinary honor of being elected to the Academie Française. In parallel with but independently of Einstein, who, for some reason, he seemed to dislike, Poincaré in 1906 published a theory of the electron from which many of the central conclusions of Einstein's (1905) special theory of relativity follow, though on totally different grounds.

Polanyi, Michael (1891–1976). Polanyi was a Hungarian physical chemist of note who moved to England in 1933, exchanging a research position at the Kaiser Wilhelm Institute for a chair in chemistry at Manchester University. With the outbreak of World War II and the rise of communism, Polanyi shifted his attention to philosophical issues of scientific knowledge, exchanging his chair in chemistry for one in social studies. His focus on the "tacit" knowledge a scientist acquires through education and participation in the activities of the scientific community led to his critique of the traditional view of scientific knowledge.

Popper, Karl (1902–1994). Viennese by birth, Popper fled Vienna after the Nazi annexation of Austria for New Zealand and, after the translation into English of his prewar magnum opus, *The Logic of Scientific Discovery*, became a highly influential professor at the London School of Economics. Popper was an aggressive opponent of Freudianism and Marxism, both of which he considered pseudo-scientific. (See his *The Open Society and Its Enemies*.) Best known for his falsification criterion of scientific knowledge, Popper also taught that the discovery process in science was fundamentally non-logical and unpredictable and that confirmation of knowledge claims could only be justified probabilistically.

Protagoras (c. 480–411 B.C.E.). With Gorgias, Protagoras was the greatest of the Sophists, who developed and defended a relativist, action-oriented theory of rationality, truth, knowledge, and values. Plato and Aristotle mocked Protagoras for having taught that "Man is the measure of all things," arguing that this meant that truth was anything people chose to make it, but as Fleck noted, scientific explanation necessarily begins with quantitative measures and conceptual assumptions introduced by scientists.

Ptolemy, Claudius (2nd century). A Greek who lived and worked in Alexandria, Ptolemy formulated the definitive mathematical version of the Earth-centered theory of the heavens that dominated Western and Islamic astronomy from antiquity until a century after Copernicus offered his Sun-centered alternative. His book, nicknamed by Islamic followers the *Almagest*, or "Great Book," was the standard astronomy reference and textbook for 1,400 years. His book *Geography*, showing how to make relationally accurate two-dimensional maps of Earth's spherical surface, was rediscovered and published to great acclaim in the early 16th century, influencing mapmaking at the dawn of the European voyages of discovery.

Putnam, Hilary (1926–). A leading American philosopher, trained in mathematics and mathematical logic and an important contributor to those fields, as well as to philosophy of science and philosophy generally. Like Bertrand Russell, Putnam has changed his philosophical position several times in his career, each time leaving a lasting influence. A professor at Harvard, Putnam and Saul Kripke at Princeton proposed an objectivist-realist account of scientific knowledge; later however, in his book *Realism with a Human Face*, he argued for a view of scientific knowledge as a necessarily non-unique account of experience that was objective but not because of claims that it corresponded with a reality beyond experience. He subsequently qualified his commitment to this view, too, reflecting that the correct predictions made by scientific theories would be miraculous coincidences if scientific knowledge were not objectively anchored in reality.

Quine, Willard van Orman (1908–2000). One of the most influential American philosophers of science, Quine was trained in mathematical logic and philosophy, studying under Alfred North Whitehead at Harvard and, in Europe, under the Logical Positivist Rudolf Carnap. Though his article "The Two Dogmas of Empiricism" was taken to have undermined the Logical Positivist theory of scientific knowledge and, together with Pierre Duhem's criticism, is a staple of the arguments by opponents of the objectivity of scientific knowledge, Quine himself never doubted that scientists produced objective knowledge of nature via experience. He attempted to anchor this objectivity in a Naturalistic Epistemology.

Ravetz, Jerome (1930–). Born in Philadelphia and trained in mathematics and philosophy at Swarthmore, Ravetz was effectively exiled to England during the McCarthy years (and long after) for having joined the American Communist Party as a teenager. He completed his doctoral degree there and became an influential academic figure, first, at the University of Bath, then, as chair of the philosophy department at the University of Leeds, promoting study of the social consequences of scientific knowledge and technology and the influence of social and political factors on the production of scientific and technological knowledge.

Russell, Bertrand (1872–1970). Russell rose to fame as a mathematical logician, exposing a fatal flaw in the German mathematician Gottlob Frege's project to reduce arithmetic to logic, then going on, with Alfred North Whitehead, to attempt an even broader reduction of mathematics to logic. Russell was a founder of the analytical philosophy movement and of Logical Empiricism, arguing that logic was the basis of objective knowledge of the world. He brought Wittgenstein to Cambridge as a protégé and kept him there even after Wittgenstein's views diverged completely from his own, which changed several times in his long career, devoted also to liberal political and social activism.

Scheffler, Israel (1923–). An American philosopher of education at Harvard University. His defense of empiricism and the objectivity of scientific knowledge against Hanson, Polanyi, and especially Kuhn was motivated by a concern for the consequences of the moral and intellectual relativism entailed by the collapse of objective truth.

Schlick, Moritz (1882–1936). A German philosopher of science influenced by Wittgenstein's early work, Schlick was committed to the objectivity of scientific knowledge as a description of reality and founded the influential

Vienna Circle of Logical Positivists. He was assassinated by a Nazi student at the University of Vienna, where he held a professorship.

Sokal, Alan (1955–). An American physicist at New York University. A Web search on "Sokal" reveals the extent of the impact of his hoax and the passions unleashed by it, for and against science.

Thompson, Benjamin/Count Rumford (1753–1814). An American colonist but a Royalist during the Revolutionary War who fled to England, where he received a pension from the king; devised a clever experiment to "prove" that heat was motion, not a fluid; and helped fund the Royal Institute to promote public dissemination of scientific knowledge. He moved to France, where he married Lavoisier's widow, then to Austria, where he played an important role in government.

Thomson, William/Lord Kelvin (1824–1907). British physicist and one of the most influential figures in 19th-century science, pure and applied. (He played a decisive role in designing and laying the first successful transatlantic telegraph cable.) Consistent with his materialist realism, he insisted that for a physical theory to be true, it needed to have a mechanical interpretation.

Turgot, Anne-Robert-Jacques (1727–1781). A founding figure in the application of mathematics, especially probability and statistics, to social and political decision-making. Turgot served all too briefly as minister of finance to Louis XIV a decade before the French Revolution erupted; he was removed from office by opponents of the radical reform policies that he argued were the only alternative to bloody revolution!

Wallace, Alfred Russell (1823–1913). A surveyor by training and a self-taught naturalist, Wallace spent years in the Amazon jungle, then more years in Malaya as a specimen hunter for wealthy British collectors of rare plants, insects, birds, and animals. His co-creation of evolution by natural selection was based on biogeography rather than on fossils and selective breeding, as Darwin's was. He became a prolific author, a major figure in British science, and a champion of liberal social reform but broke with Darwin over the inclusion of man in the evolution of life and defended spiritualist views.

Whewell, William (1794–1866). Whewell was a scientist, contributing to the development of crystallography, but was more influential as an educator, as a theorist of science through his books on the history and philosophy of science, and as a champion of science education reform in England, both at the university level and for the general public through the creation of the British Association for the Advancement of Science. Among many other now-familiar scientific terms, he coined *scientist*. His hobby was German church architecture.

Wittgenstein, Ludwig (1888–1951). Born in Austria and trained as an engineer, Wittgenstein moved to Cambridge University to pursue the application of mathematical logic to philosophical problems of knowledge under the influence of Bertrand Russell. He served as a medic in the Austrian army during World War I and, later, as a schoolteacher in Austria before returning to Cambridge in the 1930s. After that time, his philosophical views were taken as a complete repudiation of his early work that stimulated the rise of Logical Positivism as a theory of scientific knowledge. An extremely eccentric personality, his uncompleted book *Philosophical Investigations*, published posthumously in 1953, and the publication of the many notebooks he left behind have made him the single most influential philosopher of the second half of the 20th century.

Science Wars: What Scientists Know and How They Know It

Part II

Professor Steven L. Goldman

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Steven Goldman has degrees in physics (B.Sc., Polytechnic University of New York) and philosophy (M.A., Ph.D., Boston University) and, since 1977, has been the Andrew W. Mellon Distinguished Professor in the Humanities at Lehigh University. He has a joint appointment in the departments of philosophy and history because his teaching and research focus on the history, philosophy, and social relations of modern science and technology. Professor Goldman came to Lehigh from the philosophy department at the State College campus of Pennsylvania State University, where he was a co-founder of one of the first U.S. academic programs in science, technology, and society (STS) studies. For 11 years (1977–1988), he served as director of Lehigh's STS program and was a co-founder of the National Association of Science, Technology and Society Studies. Professor Goldman has received the Lindback Distinguished Teaching Award from Lehigh University and a Book-of-the-Year Award for a book he co-authored (another book was a finalist and translated into 10 languages). He has been a national lecturer for Sigma Xi—the scientific research society—and a national program consultant for the National Endowment for the Humanities. He has served as a board member or as editor/advisory editor for a number of professional organizations and journals and was a co-founder of Lehigh University Press and, for many years, co-editor of its Research in Technology Studies series.

Since the early 1960s, Professor Goldman has studied the historical development of the conceptual framework of modern science in relation to its Western cultural context, tracing its emergence from medieval and Renaissance approaches to the study of nature through its transformation in the 20th century. He has published numerous scholarly articles on his social-historical approach to medieval and Renaissance nature philosophy and to modern science from the 17th to the 20th centuries and has lectured on these subjects at conferences and universities across the United States, in Europe, and in Asia. In the late 1970s, the professor began a similar social-historical study of technology and technological innovation since the Industrial Revolution. In the 1980s, he published a series of articles on innovation as a socially driven process and on the role played in that process by the knowledge created by scientists and engineers. These articles led to participation in science and technology policy initiatives of the federal government, which in turn led to extensive research and numerous article and book publications through the 1990s on emerging synergies that were transforming relationships among knowledge, innovation, and global commerce.

Professor Goldman is the author of The Teaching Company course *Science in the Twentieth Century: A Social Intellectual Survey* (2004).

Table of Contents

Science Wars: What Scientists Know and How They Know It
Part II

The 20th Century

Science Wars:
What Scientists Know and How They Know It

Scope:

The objective of this course is to explore, in depth, the nature of scientific knowledge and of the claims to truth that scientists make on behalf of their theories. Are scientific theories true because they correspond to reality? How can we know that they do, given that we have no access to reality except through experience, which scientists themselves tell us is profoundly different from the way things "really" are? Are theories true because they account for experience and make correct predictions? This sounds plausible, but theories that we now consider wrong once were considered true because they accounted for our experience and made successful predictions then! Should we assume that as new experiences accumulate, current theories will be replaced, as all previous theories have been? But in that case, theories are not really knowledge or truth, in the strict sense of those words, but a special case of experience-validated educated opinion.

These are more than just intellectually interesting questions. The roles that science has come to play in contemporary society and world affairs make the answers to these questions important to society, particularly to the citizens of democratic societies who have an opportunity and an obligation to influence science policy decisions. Furthermore, since the 1960s, science has come under broad political, intellectual, and religious attack—erupting in the 1980s in what was called the "Science Wars"—even as it achieved unprecedented recognition and support as both critical to social well-being and the crown jewel of Western cultural achievement.

The first lecture in this course describes the post-1960 attacks on science and relates them to conflicting conceptions of knowledge, truth, and reality in the history of modern science and, more broadly, in the history of Western philosophy.

Lectures Two through Five are devoted to the 17th century and the conflicting conceptions of scientific knowledge promoted by the "founding fathers" of modern science: Francis Bacon, René Descartes, and Galileo Galilei. It quickly becomes clear that there was then, and is now, no such thing as "the" scientific method, no one method that can transform naive empirical experience into knowledge of nature.

Lectures Six, Seven, and Eight are devoted to 18th-century responses by nonscientists to the growing acceptance of Newtonian science as the truth about reality, climaxing in the Enlightenment proclamation of an Age of Reason with science as its living model. The central figures in these three lectures are John Locke, Bishop George Berkeley, David Hume, and Immanuel Kant.

It was in the 19th century that modern science truly came of age, with the formulation of theories in physics, chemistry, and biology that were far more sophisticated, abstract, powerful, and useful than 17th- and 18th-century theories. But for those very reasons, these theories made more pertinent than before questions about the nature, scope, and object of scientific knowledge. What were these theories about, given that the reality they described was so different from human experience; given, too, the need for increasingly complex instruments to access this reality and the increasingly esoteric professional languages in which scientific descriptions of the world were formulated? Lectures Nine through Twelve are devoted to the range of interpretations among leading scientists of what *knowledge* and *truth* mean in science, and of how they are arrived at using some combination of instruments, experiments, ideas, facts, and logic.

If the maturation of modern science was a 19th-century phenomenon, the maturation of philosophy of science, that is, of the systematic study of scientific reasoning and scientific theories as products of that reasoning, is a 20th-century phenomenon. Lectures Thirteen through Twenty-Two are devoted to exploring the rich and innovative responses to science as knowledge by scientists, philosophers, historians, and sociologists from 1900 through the early 21st century. Lecture Thirteen surveys the state of theories of science at the turn of the century, the social status of science, and its cultural impact, especially on religion and art. Lecture Fourteen traces the interpretation of science as deductive knowledge, focusing on the highly influential movement known as Logical Positivism.

The evolution of quantum theory, from Planck's initial tentative hypothesis through the formulation of quantum mechanics in the mid-1920s, raised new questions about the relationship of science to reality, as well as about the ability sharply to distinguish objectivity and subjectivity. Lecture Fifteen addresses these questions, which continue unresolved to this day. Concurrently, a number of thinkers inside and outside of science began reassessing the claim of science to possess universal, objective truths about nature. Lectures Sixteen through Eighteen explore this reassessment, moving from interpretations in the 1930s of social influences on what we accept as knowledge to historicists' interpretations of scientific knowledge just before and after 1960.

Lectures Nineteen through Twenty-Two explore the increasingly aggressive critiques of scientific knowledge from the 1970s through the 1980s, climaxing in the Science Wars of the 1990s. They describe both the postmodernist attack on science and new attempts to defend science as a privileged form of knowledge and truth.

Lectures Twenty-Three and Twenty-Four address the creationism-intelligent design versus evolution controversy in light of contemporary interpretations of science and the implications of these interpretations for science policy and rational action as we enter the 21st century.

Lecture Thirteen

Scientific Truth in the Early 20th Century

Scope: In the 19th century, the nature of scientific knowledge was recognized as a problem for science and was addressed by scientists. In the 20th century, this changed and in this lecture we begin to trace this change. As science and philosophy both became increasingly professionalized and specialized, increasingly it was philosophers who took up the problem of justifying scientific knowledge, but as a philosophical problem and in philosophical terms. Paradoxically, science became more and more important to society in the course of the 20th century and received unprecedented social support. However, the specialization of scientific practice and the rapid advance of scientific knowledge outstripped all efforts to create a scientifically "literate" public, capable of informed participation in science policy decisions. At the same time, new scientific theories, most famously the relativity and quantum theories, were forcing a fundamental reconceptualization of reality and of the logic of scientific reasoning. Three thinkers illustrate the early- 20th-century turn in addressing the question "What do scientists know and how do they know it?": the French mathematician Henri Poincaré, the British logician and philosopher Bertrand Russell, and the American physicist Percy Bridgman.

Outline

I. Centuries are an artificial periodization of history, but knowing this, we still expect the turnings of centuries to correlate with changes in social phenomena.

- **A.** In the 19th century, scientists played the lead role in justifying scientific knowledge claims. In the 20th century, philosophers took over this role.
    - **1.** Beginning in the second half of the 19th century, science started to deliver on the Baconian-Cartesian promises of power over nature.
    - **2.** By the end of the century, chemistry had created whole new industries: synthetic dyes, plastics, explosives, pharmaceuticals, and fertilizers.
    - **3.** The cell theory of life, germ theory, antiseptics, and anesthesia were laying the groundwork for scientific medicine.
    - **4.** Physics was at the heart of new communication, power, and transportation technologies.
- **B.** The creation of the industrial research laboratory marked an epochal marriage between science and technology.
    - **1.** The industrial research laboratory recognized a direct connection of mutual enrichment between theory and practice, promoting the perception that scientific knowledge "drove" technological innovation, and that innovation was, as Bacon said it would be, the "fruit" of "true" knowledge of nature.
    - **2.** Successful innovation, in turn, seemed validation enough of scientific knowledge claims.
    - **3.** The science-innovation connection reinforced basing engineering education on science, mathematics, and laboratory experience, which affected the professionalization of science.
- **C.** Science became deeply embedded in the life of the *polis*, increasingly so in the course of the century.
    - **1.** The explosive growth of industrialization required a matching increase in engineers and in both scientists and mathematicians to train them, and institutions at which to train them.
    - **2.** The rise of research-based academic institutions is directly tied to this development, creating new public expectations from public support of knowledge.
    - **3.** After World War II especially, science became integrated into the fabric of social life through its role in education; into political life by abetting governmental, military, and economic agendas; and into economic life by underpinning the creation of wealth and power through its link to technological innovation.

II. Ironically, just as science increasingly mattered in practical ways to the general public, and for that reason scientific knowledge was accepted as true, the 19th-century scientific theories responsible for this perception were being discarded!

- **A.** The special and general theories of relativity, quantum theory, and genetics proposed sweeping revisions in what 19th century scientists thought was true and real.
  - **1.** What, after 200 years of modern science, we thought we knew about reality was wrong.
  - **2.** We might well wonder what grounds there were for confidence that what scientists *now* thought was true and real truly was true and real, once and for all?
- **B.** There is yet another echo here of Fourier's move.
  - **1.** The criterion that a theory is true and corresponds to what is real cannot be productivity, that the theory "works" in practical applications and makes successful predictions.
  - **2.** Theories that in the early 20th century had made science famous and prestigious because they "worked" were now being dismissed as false, as not corresponding to the way things "really" were.
  - **3.** As with Fourier, claiming that a theory corresponds to reality requires a different criterion for justification than the claim that the theory correctly describes how phenomena behave.
  - **4.** Early 20th-century science described a totally different world from that described by 19th-century science. Did scientists have knowledge *then*? Did they have it *now*? It depends on what you mean by *knowledge*!

III. Three interesting turn-of-the-century solutions to the problem of scientific knowledge were offered by Henri Poincaré, Bertrand Russell, and Percy Bridgman.

- **A.** Henri Poincaré was one of the giants of modern mathematics, an important contributor to physical science, and deeply concerned with the problem of the nature of scientific knowledge.
  - **1.** The "only true objective reality," according to Poincaré is the "internal harmony" of the world, and our knowledge of this harmony is made possible by mathematics, which provides scientists with a "convenient" language for describing it.
  - **2.** *Convenience* is different from *conventional*, the former implying a closer coupling of concepts to experience.
  - **3.** *Objective reality* is that which, in fact, is common to many thinkers and in principle could be common to all who make the effort.
  - **4.** What science gives us knowledge of is not an independently existing reality, but a commonly conceptualized experiential world.
- **B.** Percy Bridgman was both a highly decorated scientist and an influential thinker *about* science.
  - **1.** Bridgman was deeply impressed by the motivating insight underlying Einstein's relativity theories, namely, the centrality of measurement operations to the reconceptualization of space and time, and through them of motion, matter, and force.
  - **2.** Bridgman called his theory of science *operationalism*: A scientific concept means the set of operations specified for measuring it.
  - **3.** He argued that the object of scientific knowledge was not reality but a product of the network of operationally analyzed and unanalyzed concepts that scientists choose to use to explain, predict, and control experience.
- **C.** Bertrand Russell was a founder of mathematical logic and a pioneer philosopher of science. He can be said to mark the transition from scientists addressing their perception of the problem of scientific knowledge to philosophers addressing that problem.
  - **1.** Russell argued that logic was the key to knowledge of reality, together with "atomic" facts given in sense experience, and that it was possible to reduce all thought to a symbolic language of atomic propositions and logical connectives that observed a simple set of rules for truth and falsehood.
  - **2.** This symbolic language can, in principle at least, be put into a one-to-one relationship with the world because the world, for Russell, is the sum of a (very, very large) number of logically independent facts.

3. Russell influenced the Logical Positivist theory of science and the analytical philosophy movement.

Recommended Reading:

Henri Poincaré, *The Value of Science*.

Bertrand Russell, *Our Knowledge of the External World*.

Questions to Consider:

1. Is there a "natural" relationship between science and society, and if so, does it derive from the nature of science or society?
2. According to Poincaré, "objective reality" is that which is shared by many thinkers and in principle open to all willing to think the way the scientific community thinks. But doesn't this mean that "objective reality" is a product of a particular way of thinking and not either truly objective or about reality at all?

Lecture Fourteen

Two New Theories of Scientific Knowledge

Scope: The dominant view of science in the early 20th century was that science alone was knowledge, providing the only rational account of the world. In one sense, this marks the triumphant ascent of science as the sole arbiter of truth and knowledge on any subject within its scope, and in the course of the century, that scope expanded to coincidence with reality. In another sense, however, scientism and its rigorously physicalistic-deterministic account of reality—including human being in the world—seems manifestly dogmatic rather than scientific. Every effort, from the side of science and from the side of philosophy, to establish that science is knowledge in the strict philosophic sense of universal, necessary, and certain foundered on the absence of a criterion for the correspondence of scientific truth claims with reality. But the view that science was "merely" a conventional account of experience failed to convince because of the growing predictive power of new scientific theories and the increasing control over nature they conferred through technology. Can science be both irreducibly conjectural and still be knowledge? The most aggressively "pro"-science philosophies of science in the first half of the century were Logical Positivism, which embraced scientism, and Pragmatism, a "homegrown" American philosophy that rejected it.

Outline

I. By 1930, science was firmly entrenched in Western culture as a privileged source of knowledge, truth, and rationality.

- **A.** Many scientists and nonscientists alike wanted to cast science in this light and dismissed narrowly empirical, instrumental, and conventionalist interpretations of scientific knowledge.
    - **1.** Within science, the view that all manifestations of nature, including life and consciousness, were deterministic and "mechanical" in a broad sense was effectively ubiquitous.
    - **2.** It is reflected in the spread of reductionism, the view that all the sciences in principle reduce to physics.
    - **3.** This is the legacy of the Cartesian and Laplacean worldviews.
    - **4.** A revealing symptom of scientism is V. I. Lenin's attack on conventionalist interpretations of science in defense of a strict Marxist materialistic determinism and Stalin's Marxism-based objections to the relativity and quantum theories.
- **B.** The problem posed by science is simple and, as we have seen, was well known in the 17th century, yet it persisted unresolved.
    - **1.** To qualify as knowledge of nature, scientific "truth" must mean correspondence with the way things are in the world beyond experience.
    - **2.** We have no criterion of correspondence, and successful prediction does not guarantee correspondence.
    - **3.** However, conventionalist theories of science make prediction and control seemingly miraculous.
- **C.** Common sense suggests that given these extreme interpretations, the truth lies somewhere in between.
    - **1.** Given recognition of the problem, why has the insistence that science gives us knowledge of reality persisted?
    - **2.** What do we lose if we acknowledge that science is terminally conjectural and fallible but, at any given time, offers effective causal-explanatory accounts of experience validated by prediction and control?
    - **3.** How are our expectations from, and understanding of, what we mean by objectivity, reason, truth, knowledge, and reality affected by agreeing that scientific knowledge is contingent, probable, and culturally conditioned?

II. Pragmatism, especially as developed by John Dewey, offered a science-based account of knowledge along these commonsense lines.

- **A.** Pragmatism interprets knowledge as a distinctive form of action-related belief.
    - **1.** Charles Sanders Peirce was the creator of Pragmatism. He argued that the meaning of our ideas and concepts was to be sought in their implications for how we act.

    2. This links our thinking to the world through action, rather than opposing mind to world.

- **B.** William James, in *Pragmatism* and in *The Meaning of Truth*, and John Dewey co-opted Peirce's initial insight, and Dewey developed a comprehensive philosophy based on a "scientific" response to experience.
    1. Necessary, certain, and universal knowledge of what lies beyond experience, or of experience, is impossible.
    2. What we can have are warranted "beliefs," effective means of acting on experience in order to produce desired outcomes in future experiences.
    3. Unlike (philosophical) knowledge, beliefs are intrinsically dynamic because they are ends-motivated, action-oriented, and coupled to experiences that are constantly changing, only in part through our own actions.
    4. Dewey called Pragmatism prospective empiricism, highlighting its progressive, and optimistic, character.
- **C.** Dewey argued that science, properly understood as a pragmatic belief system, needed to be made the cornerstone of philosophy.
    1. Knowledge, for Dewey, was contextual and irreducibly "perspectival," expressive of selective attention to subsets of experience.
    2. The actual scientific method, then, is feeding the results of our action-oriented thinking back into that thinking. The experimental method is only one instance of this more generic conception of reasoning about experience.

III. Pragmatism was a philosophy built on an experience-based conception of scientific knowledge. From the 1920s through the 1950s, Logical Positivism was a more influential reality-based theory of science.

- **A.** Influenced by Russell and his erstwhile protégé Ludwig Wittgenstein, Moritz Schlick, at the University of Vienna, and later, Hans Reichenbach, at the University of Berlin, attracted extraordinarily gifted men with advanced training in science and philosophy to the problem of scientific knowledge.
    1. Their movement, Logical Positivism (LP), took as its mission justifying scientific knowledge as necessary, universal, and certain knowledge.
    2. LP ignores the process of discovery in science as irrelevant and focuses on the process of justification of scientific theories as true.
    3. Scientific theories must have a deductive logical structure in order to satisfy the criteria of knowledge, and so the problem for LP is the by now familiar one of justifying the move from the particular data of empirical experience to the universal premises of deductive arguments.
- **B.** LP sought to justify science as knowledge in the Platonic sense via the ideas of Russell and Wittgenstein on sense data and on "picturing" the world as an ensemble of independent, "atomic" facts, using the new relativity and quantum theories as models.
    1. LP's solution to the problem of scientific knowledge rests on an absolute distinction between theory statements (which have empirical content and implications but whose truth is not derived from that empirical content) and "pure" observation statements.
    2. To this distinction must be added a set of rules for correlating theory statements and observation statements in a given theory and a verifiability criterion of meaning.
    3. That is, a statement is only meaningful if one can specify how the truth of that statement could be verified observationally.
    4. A scientific theory is then an axiomatic system in which all relevant observation statements can be deduced from a set of logically consistent, true theory statements, in accordance with a set of mutually agreed upon rules for correlating theory and observation statements by "carrying" empirical content from the latter into the former.
- **C.** Developing this bare outline into a functional theory of scientific knowledge required works of genius, but in the end, LP failed.
    1. Schlick himself gave up on reality as the object of theories, and Otto Neurath formulated a theory of scientific truth as an internal logical property of theories as systems of propositions about the world.

2. Carl Hempel criticized the separability of theory and observation statements, and W. V. O. Quine dismissed the distinctions between analytic and synthetic sentences, and between theory and observation statements.
3. The verifiability criterion of meaning was also attacked: Some nonverifiable terms were inevitable in meaningful theories.
4. LP remained at the forefront of philosophy of science from the 1930s into the 1960s, perhaps in part, at least, because it offered hope that a classically objective theory of scientific knowledge was possible.

Recommended Reading:

John Dewey, *Experience and Nature.*

A. J. Ayer, *Language, Truth and Logic.*

Questions to Consider:

1. Is Western culture distinctive in the emphasis it places on objectivity and truth?
2. What does it tell us about ourselves that a philosophical school that, in retrospect, seems clearly wrong could for decades have attracted many of the most gifted minds in philosophy and exerted great intellectual influence throughout the West?

Lecture Fifteen

Einstein and Bohr Redefine Reality

Scope: Notwithstanding the number of physicists and philosophers who concluded that scientific theories were not "pictures" of a reality independent of experience, science continued to develop as if the opposite conclusion were self-evident! In the face of a flood tide of new discoveries in the physical, life, and social sciences, an "imperialistic" conviction continued to spread that science alone was progressive, offered truth and knowledge, and defined rationality. Quantum theory reduced chemistry to physics. Molecular biology reduced life phenomena to chemistry and physics. Scientific psychology extended to the mind the principles of physical science, and in the last third of the century, there was a further extension to social life and values. Ironically, mathematics simultaneously came under critical scrutiny from mathematicians who discovered that they could not reach a consensus on the nature of mathematical truth. While many dramatic scientific discoveries, for example, in astronomy, chemistry, and biology, lent themselves to a realist interpretation of scientific knowledge, others, such as quantum theory, challenged a realist interpretation. Albert Einstein and Niels Bohr, co-founders of the quantum theory, engaged in an epic argument over what constituted a scientific explanation of experience.

Outline

I. Logical Positivism (LP) failed to provide a realist theory of scientific knowledge, but its dominance within philosophy of science from the 1920s into the 1960s was symptomatic of the spreading perception of science as uniquely the way to truth and knowledge.

- **A.** Logical Positivism persisted in spite of the awareness by its supporters of the many scientist critics of the Platonic view of scientific knowledge.
  - **1.** The support for Logical Positivism came from those who saw themselves as defenders of scientific knowledge as an objective account of reality against those critics.
  - **2.** Increasingly, however, the people paying attention to this "battle" were not scientists, but philosophers.
- **B.** Logical Positivism could be said to have evolved from being about science to being about philosophy.
  - **1.** The institutionalization, professionalization, and specialization of science in the 20th century shifted scientists' attention away from abstract philosophical questions to "just doing" science.
  - **2.** The "imperialism" of science as the sole source of knowledge and truth challenged the very existence of philosophy, historically the discipline committed to knowledge and truth.
  - **3.** John Dewey argued that Western philosophy was dominated by a "quest for certainty", so Logical Positivism fit squarely into that dominant line of philosophical thought, and it gave philosophy a place in a era dominated by science.
  - **4.** Pragmatically, however, knowledge is not Platonic and, hence, Logical Positivism is misconceived, and wrong.
- **C.** In spite of cogent criticism, however, the realist-objectivist view of scientific theories is difficult to dismiss.
  - **1.** Scientific discoveries reinforce the realist view.
  - **2.** The discovery of radioactivity and of X-rays, for example, seem plainly to be new facts about reality.
  - **3.** The changing conception of the universe in the 1920s seems clearly to imply a new understanding of reality on the cosmic scale.
  - **4.** The bitter conflict between Mach and Boltzmann over the reality of atoms ended with victory for the realist view.
  - **5.** The relativity and quantum theories were actively promoted as new, definitively correct, theories of the way things were.

- **D.** The response to scientific discoveries and theories as revealing reality in spite of cogent criticisms of that view is itself revealing.
  - **1.** For one thing, it reveals a resistance to recognizing the historicity of scientific knowledge claims.
  - **2.** For another, it reveals a resistance to recognizing the role of contingent assumptions in organizing scientific inference deductively, and that these assumptions change over time.
  - **3.** Finally, it reveals a resistance to acknowledging that scientific knowledge is in principle and inescapably hypothetical, conjectural and corrigible.

II. The relativity and quantum theories fundamentally altered the worldview of 19th-century physics.

- **A.** Both the special and general theories of relativity (STR and GTR) are classical theories, but they redefine the classical conception of reality.
  - **1.** STR and GTR are both deterministic theories that lend themselves to a realistic interpretation. That is, both theories seem to offer "pictorial" accounts of what is real at the level of space, time, motion, matter, and energy.
  - **2.** But as a picture, STR and GTR describe a reality wholly different in its constitution from the picture offered by 19th-century physics, even though both accounts are lawful, explanatory, and causally predictive in the same sense.
  - **3.** Space and time, matter, energy, and gravity all lose their status as independent entities, and the Universe becomes finite.
- **B.** STR and GTR describe a wholly new world, yet they were assimilated by the scientific community as if they were extensions of 19th-century physics.
  - **1.** Relativity theory is not merely an *improvement* of Newtonian physics; it redefines the most fundamental terms of that physics and in the process it redefines reality.
  - **2.** Scientists behave as if theory change were a continuous process instead of discontinuously changing what we consider real.
  - **3.** The commonsense notion that the real is the changeless source and cause of experience is belied by the continual redefinition of "reality" as scientific knowledge evolves.
  - **4.** This returns attention to what I called in the last lecture a "scientific object," as opposed to the common sense objects of ordinary experience.
- **C.** Although a foundational contribution to quantum theory, Einstein's 1905 paper explaining the photoelectric effect is particularly relevant to the "pictorial"/realist interpretation of scientific theories.
  - **1.** Max Planck had announced an equation that solved a long-standing problem in physics by assuming that electromagnetic energy could only be absorbed or emitted in discrete units (*quanta*).
  - **2.** Einstein later argued that the photoelectric effect could be explained by adopting a particle theory of light in which the energy of the light particles/quanta was a function of their frequency, in accordance with Planck's equation.
  - **3.** However, Einstein warned, a scientific theory cannot be descriptive of reality if it contains mutually exclusive concepts; thus, before using Planck's equation, Einstein re-derived it in a conceptually consistent manner.

III. Einstein's new quantum theory of light was realist, a theory of what light *was*, not merely a theory of how it behaved: For that, Einstein did not need to re-derive Planck's equation! Quantum theory, however, soon became difficult to interpret pictorially.

- **A.** In spite of the opening paragraph of his photoelectric effect paper, Einstein's quantum theory of light itself contained a conceptual inconsistency.
  - **1.** Einstein had written that the physics of particles and the physics of waves are fundamentally incompatible, but his light quanta were particles that also had a frequency, and hence a wavelength, that determined their energy.
  - **2.** In certain experimental situations, these light quanta behaved just like particles; in others, just like waves. Everyone agreed that nothing physically real could *be* both a particle and a wave, yet the theory enjoyed ever increasing explanatory and predictive success.

    3. This *wave-particle duality*, as it was called for a long time, was paradoxical if the duality were attributed to the quanta (subsequently named *photons*), but Niels Bohr proposed that the duality was attributable to us.
    4. Bohr argued that with quantum theory we had "bumped up" against a fundamental limitation of the subjectivity-objectivity distinction and had to acknowledge that experience was the object of scientific knowledge, not "reality."

B. The quantum theory of matter-energy began in 1912 and has since become the core theory of physics and chemistry, with increasing applications in biology and psychology.

1. Bohr's foundational rules for his quantum theory of orbital electrons were explicitly invented and wholly justified by the fact that relevant experimental "facts" can be deduced from them.
2. In this, the early quantum theory, which assigned properties to elementary particles that would allow the available data to be derived from them, was like STR and GTR, in that Einstein made puzzling empirical equalities into principles of nature.
3. "Quantum mechanics" was the name given to the independently formulated, apparently different, quantum theories of Werner Heisenberg and Erwin Schrödinger.

C. Heisenberg's acausal matrix mechanics and Schrödinger's causal- deterministic wave mechanics proved to be intertranslatable.

1. Here we have another echo of Fourier: theories whose equations match empirical experience but whose terms have no obvious correlation with "reality."
2. Einstein and Bohr engaged in an epic, decades long argument over the explanatory adequacy of quantum theory.
3. What was at issue seems to have been different conceptions of the criteria of the intelligibility of experience.
4. The dispute illustrates the persistence of the hunger for certainty and Truth within science against pragmatic views.

Recommended Reading:

Stewart Shapiro, *Thinking about Mathematics.*

Amir Aczel, *Entanglement: The Greatest Mystery in Physics.*

Questions to Consider:

1. Given the minute fraction of the population that has any functional understanding of science today, why is science respected as much as it is?
2. Do statistical correlations that ignore causal mechanisms explain, or are they empirically valid placeholders until a causal-deterministic theory can be formulated?

Lecture Sixteen

Truth, Ideology, and Thought Collectives

Scope: The conviction that humans are, first of all, "ones" and only secondarily social is central to modern Western culture. Social contract theory and social atomism are political corollaries of this conviction. Another corollary is that thinking is individual, the product of processes internal to each individual for which they are responsible and, thus, accountable. It follows that knowledge, too, is individual, something that is created and possessed by individuals who do the hard work necessary to get it. Descartes claimed that we knew and controlled our own minds, but Montesquieu argued that environmental factors influenced ideas and values, and Herder argued for the historicity of all of culture. Comte argued for the historical development of the mind, and Marx and Engels that material factors determined consciousness, while for Pragmatism, thinking was a conditioned response to experience. In the 1930s, reinforced by linguistic and cultural anthropological theories, it was increasingly argued that thinking and knowledge were collective phenomena. Karl Mannheim proposed that all thinking was "ideological" *except* thinking in science and mathematics, and Robert Merton analyzed the role of religious belief in early modern science. But the most radical theory of scientific knowledge appeared in 1935, in a work little noted until the 1960s.

Outline

I. Individualism seems to be one of the core doctrines of the Western cultural tradition, but from its rebirth in the Renaissance, it has been challenged.

- **A.** Descartes, as a "father" of both modern philosophy and modern science, was committed to an individualist theory of knowledge.
    - **1.** To be human for Descartes is to be a thinker: Thinking is what we do, and the mind is the basis of who we are; the material world, including our bodies, is what we are not.
    - **2.** The key to Descartes theory of knowledge is the transparency of mind to itself, in principle, when an appropriate critical methodology is employed. That is, the mind can know itself fully.
    - **3.** Thus, thinking is an individual activity absolutely distinct from the world, which stands over against thought—subjectivity and objectivity, as we use those terms, are distinct and have nothing in common—and knowledge of the world forms within each thinker making the effort to acquire it.
- **B.** This view was already being challenged in the 17th century, but the challenges grew in the 18th and 19th centuries.
    - **1.** More rigorous materialists than Descartes defended materialistic theories of mind in which thinking was a deterministic, mechanical phenomenon, a form of calculation.
    - **2.** David Hume denied the existence of the Cartesian self and formulated a psychology in which the contents of mind were determined by laws of association between sensory inputs and memories of past experiences.
    - **3.** Étienne Condillac proposed a radically empirical theory of consciousness in which mental abilities no less than ideas are acquired through experience.
    - **4.** Pierre Cabanis, among other pioneer neuroanatomists, sought the material basis of mind in the structure of the brain.
    - **5.** The view that reasoning was a species of calculation also naturalized thinking.
- **C.** Individualism consolidated its place in society through 18th- and 19th-century social and political reform and the rise of industrial capitalism, but the challenges to individualist theories of mind accelerated.
    - **1.** The 19th century discovery of the unconscious, culminating in the theories of Sigmund Freud, George (Georg) Groddeck, and Carl Jung, rejected the Cartesian claim that the individual could know his/her own mind fully.
    - **2.** Gottfried Wilhelm Herder, reviving the ideas of Giambattista Vico, developed a historicist theory of ideas, values, and institutions, arguing that all of these were products of their cultural context.

        3. For Marx and Engels, each person's consciousness is determined by material factors of which, typically, they are not conscious: the technologies they use, their economic relationships, and the resultant social institutions based on those technologies and economic relationships.

II. Marx's point, inverting the teaching of Hegel, was that thought is not a neutral, private activity uncoupled from the world.

- **A.** In particular, Marx argued that intellectual activity inevitably was affected by social relationships and values.
    1. Marx was a materialist, of course, a "scientific materialist" as he thought, but he was not an individualist: Minds no less than people are social entities.
    2. Perhaps inconsistently, Marxists insisted that members of the privileged classes suffered from ideological, or "false," consciousness but that some could free themselves to initiate communism.
    3. Nietzsche's defense of a perspectival conception of ideas was echoed in Franz Boas's relativist theories in language and anthropology.
- **B.** By the 1930s, all of these developments converged on the emergence of sociology of knowledge as a new intellectual discipline.
    1. Karl Mannheim's *Ideology and Utopia* was a founding work of the new sociology of knowledge. In it, he argued that all thinking was "ideological" and that thinking was inescapably tied to the social and cultural context of the thinker, excepting only science and mathematics.
    2. Robert Merton's doctoral dissertation explored the religious affiliations of the founding members of the Royal Society of London in the 1660s, concluding that far more were Protestants than Catholics.
    3. Merton subsequently wrote extensively on the sociology of scientific knowledge, arguing that social factors influenced the form of the practice of science but *not* its content, which, as for Mannheim, was objective because it was validated by nature.
    4. A dissenting voice was that of the prominent Marxist scientist and political activist J. D. Bernal, who argued that modern science was a product of capitalism.

III. The most startling, and radical, theory of scientific knowledge to be formulated in the 1930s came from an eminent immunologist, Ludwik Fleck, who, because of restrictions on Jewish academic appointments, worked in his own research laboratory in the small Polish city of Lvov.

- **A.** Fleck's monograph *The Genesis and Development of a Scientific Fact* uses the history of syphilis and the identification of a test for it as a vehicle for exploring what scientists know and how they know it.
    1. Fleck argued that science was a fundamentally collective enterprise.
    2. Only an individual who had assimilated the values, ideas, and language of the collective could be recognized as thinking scientifically.
    3. From 1500 to the early 1900s, the medical community's identification, definition, and conceptualization of syphilis changed in ways that reveal the influence of social values as well as professional assumptions on scientific concept formation.
    4. Scientists typically accept names as referring to "things" with well-defined, fixed properties, when they may refer only to ill-defined patterns in data, whose relevance also may be ill-defined.
- **B.** Fleck identified a still more fundamental level at which the mind is revealed to be active in reasoning about experience and not passively responsive, as in Empiricism.
    1. All scientific reasoning and all scientific "facts" necessarily display "active associations" and "passive relations." What we call a "fact" in the context of a scientific explanation/theory inevitably is more than a "mere" observation.
    2. We cannot begin reasoning without actively imposing some measures, some criteria of relevance, and some rules/principles on the phenomena we are reasoning about.
    3. Once the active associations have been adopted, and these are conventional in that nothing in the phenomena forces us to adopt them, then the passive relations follow objectively, necessarily.
    4. Again we see a recognition that the assumptions that allow scientific theories to have a deductive character are themselves contingent.

- **C.** Science, Fleck concluded, is an essentially social enterprise, an enterprise practiced by a community whose members share ideas and values.
    - **1.** Fleck called such a community a “thought collective.”
    - **2.** He called the general form of the thinking of such a collective, a “thought style,” expressive of the concepts, values, and methods accepted by a collective at a particular time as valid.
    - **3.** Evolutionary biology and quantum theory would be examples of thought styles that emerged and developed at the hands of growing thought collectives.
    - **4.** Fleck anticipated Thomas Kuhn’s epochal book *The Structure of Scientific Revolutions*.

Recommended Reading:

Ludwik Fleck, *The Genesis and Development of a Scientific Fact.*

Alain Renaut, *The Era of the Individual.*

Questions to Consider:

1. Given the obvious reality and necessity of social relationships for the survival of individuals, how does individualism come to be so highly valued in Western societies?
2. Individuals speak, of course, but speech is an intrinsically social act that one must learn to perform so as to meet the expectations of others. Is science an analogous social act and, if so, then what are the implications of the science socialization process for the objectivity of science?

Lecture Seventeen

Kuhn's Revolutionary Image of Science

Scope: The publication in 1962 of Thomas Kuhn's *The Structure of Scientific Revolutions* precipitated a radical change in intellectuals' attitudes toward scientific knowledge. Kuhn argued that the history of science compelled a reassessment of the prevailing "image" of science as converging on a uniquely correct account of reality. Kuhn focused on theory change, claiming that on the historical record this process was discontinuous, "revolutionary" in his language. Logic and data together were inadequate to require abandoning a prevailing theory or accepting a new theory. Inevitably, the new theory was a reinterpretation of nature, acceptance of which entailed nonlogical judgments, for example, the acceptance of new assumptions, rules, and/or principles of nature. As interpretation is a fundamentally nonunique process, scientific knowledge is, in Kuhn's view, not objective in the classical Empiricist sense. Kuhn proposed a theory of science that made the formation, explication, undermining, and replacement of conceptual frameworks—"paradigms" as he called them—a continuous, nonconvergent (but nevertheless progressive) process.

Outline

I. Kuhn's *The Structure of Scientific Revolutions* precipitated a reassessment by intellectuals of the privileged status of scientific knowledge and, more broadly, of the possibility of true objectivity.

- **A.** The response to Kuhn's book reveals as much about the social context in which it appeared, as it does about the power of the book's ideas.
  - **1.** There is probably no single idea or claim in Kuhn's book that had not been made before or was not being made by contemporaries of Kuhn.
  - **2.** There is a striking similarity between Kuhn's model of scientific practice and Fleck's model.
  - **3.** Kuhn's historicist critique of scientific knowledge, and his insistence that the process of discovery is central to understanding how scientific knowledge is produced because it highlights contingent assumptions, all stand in a long tradition.
  - **4.** It may well be that the social, political, and intellectual turmoil of the 1960s was more responsible for the impact of Kuhn's book than its content!
- **B.** Kuhn rejected the entrenched "story" of scientific knowledge as objective, value neutral, impersonal, universal, and converging on a true account of reality.
  - **1.** Kuhn's rejection was based on his own approach to the history of science. Ironically, Kuhn was commissioned to write *Structure* by the editors of the *International Encyclopedia of the Unified Sciences* (founded by Otto Neurath), who were Logical Positivists.
  - **2.** The history of science had achieved recognition as an academic discipline in the 20th century, and its founders considered its mission to be chronicling the progressive growth of scientific knowledge as a product of a logico-experimental method applied to experience.
  - **3.** On this traditional view, theories are replaced because they are false, that is, they misrepresent reality, and the theories that replace them are accepted because they reveal this misrepresentation while demonstrating that they represent reality (more) accurately.
  - **4.** Thus, the history of science has a linear character, characterized by the progressive elimination of errors in our understanding of nature, a corollary of which is convergence on a true understanding of nature, which remains the constant object of scientific knowledge, and its single correct description science's goal.

II. Kuhn claimed that historians of science had been asking the wrong questions, focusing on chronology, and recording who was "right" about nature and who was "wrong" as conceived by science today.

- **A.** The picture of science we get from history changes drastically when historians ask different kinds of questions, questions about the process of discovery.
  - **1.** Such questions reveal the ultimately non-logical character of this process.
  - **2.** A case in point for Kuhn was the "discovery" of oxygen by Lavoisier in the 1780s.

B. Kuhn argues that Lavoisier did not discover oxygen at all, in what I have called the archaeological sense of discovery: revealing what was hidden and waiting to be uncovered.

  1. Lavoisier reconceptualized combustion as part of a self-proclaimed revolution in chemistry that he called for.
  2. Lavoisier's rival, Joseph Priestley, interpreted the results of the same experiments as supporting the then-current, now discredited, phlogiston theory of combustion.
  3. For decades after Lavoisier's "discovery" of oxygen, Priestley and other eminent scientists of the day rejected his theory of combustion in favor of the phlogiston theory.
  4. The obvious inference is that theories that we now consider wrong were not wrong because they were unreasonable, but because they were interpretations of data that were superceded by later interpretations.

C. Kuhn's was one of several post-WWII voices arguing for a view of scientific theories as interpretations of experience rather than as descriptions of nature.

  1. We have already referred to J. D. Bernal's claim that science was "ideological," but his Marxist convictions required him to believe that under ideal (communist) social conditions, scientific knowledge would be truly objective.
  2. The chemist Michael Polanyi thoughtfully argued that "tacit" knowledge, internalized in the course of science education and winning admission into the science community, along with value judgments, were necessary for the production of scientific knowledge.
  3. Norwood Russell Hanson argued that neutral observation, unaffected by value judgments and theory (in the form of assumptions), is impossible, hence so is truly objective knowledge. People see, not eyes; and so science is an interpretive, historically rooted practice.

D. Third, Kuhn proposed a theory of scientific practice that purports to explain how scientific knowledge is produced.

  1. A new science begins with a certain amount of disciplined confusion as scientists attempt to explain new phenomena, which requires identifying relevance criteria and appropriate assumptions capable of supporting "satisfying" explanations.
  2. At some point, a *paradigm* crystallizes, the pursuit of which Kuhn called "normal science."
  3. Inevitably, as new experiments are done and new data are collected, anomalies accumulate that don't fit the paradigm, and sometimes these are perceived to be so serious that they create a crisis.
  4. Whether as worldviews or as conceptual frameworks in a positivist/operationalist sense, rival paradigms are "incommensurable" with one another, which is why scientific knowledge cannot simply cumulate across paradigms.
  5. New paradigms redefine "reality."

III. Kuhn's claims about the practice of science may be wrong in detail but his model of that practice survives.

A. Kuhn's model cannot simply be dismissed because his terminology was imprecise or because his claim of incommensurability was overstated.

  1. In every branch of every science there are clusters of related assumptions that function like Kuhnian paradigms to direct research.
  2. It is not uncommon, however, for challenging the prevailing paradigms to be a part of normal science, and paradigms themselves evolve, often changing significantly as we have seen in astronomy, the atomic theory of matter, the Big Bang theory, et cetera.
  3. Paradigms do change, and when they do, the change is attributed at least in part to anomalies, and the new paradigm does redefine what the term "reality" means now.

B. Kuhn's historicist approach gives us new and deep insights into science.

  1. Anomalies are inevitable and well-known and typically do *not* precipitate crises, but Kuhn was right that it is not possible to tell in advance whether an anomaly *will* provoke a crisis.
  2. That is, the process of theory change in response to accumulating data is an interpretive, not solely a logical, process.

3. Although rival paradigms are conceptually mutually exclusive, and thus conflict both logically and as accounts of reality, the term “incommensurable” is too strong if it is taken to mean that rivals cannot communicate scientific knowledge.
4. Scientific knowledge progresses in terms of explanatory scope, predictive success, and control but always relative to sets of assumptions that are themselves justified by those same explanations, predictions, and control. There is no independent measure of progress in the correspondence of our theories to the way things really *are*.

Recommended Reading:

Thomas Kuhn, *The Structure of Scientific Revolutions* (3rd ed.).

Michael Polanyi, *Science, Faith and Society.*

Questions to Consider:

1. If people, not eyes, see, what does it mean to say that people see the same things?
2. Why is reality so problematic for science when it is so obvious in everyday life?

Lecture Eighteen

Challenging Mainstream Science from Within

Scope: Kuhn's book appeared at a time when the natural sciences were flourishing as never before, revealing new "truths" on a scale and at a pace that was breathtaking. Undoubtedly, science gave us knowledge of the real; yet with the publication of *Structure*, it seemed that natural science, "hard" science, was vulnerable precisely in its claim to objective knowledge of reality. Reinforced by a torrent of studies by historians and philosophers of science suddenly "discovering" social influences on scientific knowledge, a number of related questions came to the fore. Are there natural metrics to experience that it is science's task to uncover, or does reasoning about experience entail projecting human metrics onto experience? Does science "speak" the language of nature, or do scientists invent languages—legitimated by explanatory power and predictive success—in order to speak about nature? Can reasoning overcome the embodiment of the reasoning mind, or is our humanness an inescapable constraint on our reasoning? The fate of what we mean by *knowledge*, *truth*, and *reality* hangs on the answers to these questions.

Outline

I. The response to *Structure* was a cultural event, with rival choruses of praise for Kuhn for opening our eyes to the myth of objective knowledge, and blame for opening the door to socially and intellectually corrosive relativism. One consequence of *Structure* was to highlight the role of assumptions in scientific reasoning.

- **A.** Are the "measures"/assumptions we apply to experience natural or artificial?
    - **1.** It is not possible to collect data and analyze them without some assumptions.
    - **2.** The assumptions ultimately serve as parameters of intelligibility: their employment satisfies us that what had been problematic in experience was now intelligible.
    - **3.** This shifts the problem of what makes scientific theories *knowledge* to identifying where assumptions, playing the role of metrics of experience, come from.
    - **4.** The process of choosing assumptions becomes visible when new theories first take shape, as string theory today.
- **B.** Recall that the overt Science Wars of the late 20th century were, I claimed, an expression of the battle for the definition of philosophy that Plato had written about in his dialogue *The Sophist*.
    - **1.** It was Protagoras and his claim the "Man is the measure of all things" who represented what Plato and Aristotle were opposed to.
    - **2.** Protagoras was, I believe, arguing that humans invent metrics that enable us to make sense of experience, to make experience intelligible to us.
    - **3.** This implies that there is no natural metric to experience, and exactly this claim has been a source of controversy in biology—in the form of what I call the taxonomy problem—for centuries.
    - **4.** Plato had anticipated the taxonomy problem by simply asserting that one of the things a true philosopher could do was to "carve nature at its joints."
- **C.** There is a fundamental philosophical issue at stake here, as well as a scientific one.
    - **1.** What we classify and how we classify, in physics no less than in biology, has profound consequences for what we think theories are about and what we think reality is.
    - **2.** In the mainstream Western philosophical tradition, our humanness ultimately is not an impediment to achieving knowledge of reality.
    - **3.** We have seen this view defended by analytic philosophers, by the Logical Positivists, and by the defenders of objectivity after them. It is central to the claim that the key to truth is method.
    - **4.** The contrary view, often called Continental philosophy, and consistent with Pragmatism, is that our humanness is inescapable, such that all organization of experience, all knowledge claims, reflect changing interests.

II. That scientific thinking has a collective character, shaped by education and professional community life, is reflected in the power of collective thinking to create us-versus-them distinctions as revealed by the careers of highly credentialed “outsiders.”

- **A.** Halton Arp is an astronomer whose outsider status comes from challenging the principle that the redshift of light is always a sign of motion.
  - **1.** For decades, Arp has argued that observational evidence links quasars with very high redshifts to features like jets of gas with much lower redshifts.
  - **2.** Some of Arp’s evidence cannot be explained on any other ground, so it is routinely explained away because the astrophysics collective has too much invested in the expanding Universe paradigm to undermine it absent *compelling* evidence.
  - **3.** So much for the Logical Positivist doctrine of verification, Karl Popper’s doctrine of falsification, and Kuhn’s doctrine of crisis-precipitating anomalies!
- **B.** The late Thomas Gold was a Cornell University physicist of considerable accomplishment but an outsider.
  - **1.** With Fred Hoyle and Hermann Bondi, Gold was one of the creators of the steady-state/expanding Universe theory, but he stayed loyal to it after the Big Bang consensus formed.
  - **2.** Gold challenged another entrenched paradigm by arguing that oil and natural gas were continually being produced by geologic and biologic processes deep within the Earth.
  - **3.** Gold correctly predicted that the lunar surface was coated with a thick layer of very fine dust, and he proposed a theory of how the inner ear works that was ignored for decades because it contradicted prevailing medical wisdom.
  - **4.** Gold’s response to his experiences was to point out that the peer review system in science reinforces what he called a “herd instinct.”
- **C.** The out-of-Africa theory of human origins is the current orthodoxy, but University of Michigan anthropologist Milford Wolpoff has been defending an alternative view.
  - **1.** The dominant view at the moment is that Homo sapiens evolved once, in east Africa, and migrated out to populate the world.
  - **2.** Based on a growing body of fossil and DNA evidence, defenders of this view argue that Homo sapiens did not mate with Neanderthal in Europe or Homo erectus in Asia, but somehow supplanted them.
  - **3.** With access to precisely the same data, Wolpoff argues for a multiregional origin for modern man, with extensive interbreeding with Neanderthal and Homo erectus.
  - **4.** The “hard” evidence is equivocal and open to interpretation, but the out-of-Africa theory has acquired the status of an established doctrine.

III. History of science teaches us that scientific theories evolve. Even Kuhnian paradigms change over time in unpredictable ways.

- **A.** We have already seen this evolution in Copernicus’s theory of the heavens and in the more recent Big Bang theory of the Universe’s origin.
  - **1.** First of all, note that the planets do not move in elliptical orbits “really,” though we routinely say that they do, and heap praise on Kepler for being the first to claim this, and on Newton for deducing the “necessity” of elliptical orbits from his theory of gravity.
  - **2.** Note, too, that the Big Bang theory, whose roots go back to the 1920s and late 1930s, and which has been transformed out of all recognition since the 1980s, has lots of anomalies, lots of things it cannot explain, yet it is nevertheless a serious scientific theory.
  - **3.** The same is true of evolutionary theory in biology and the DNA theory of genetics: the “same” theory, the same paradigm, changes over time as it confronts new data and new challenges, before being set aside for a fundamentally different theory.
- **B.** Theories unfold logically, but they also evolve and still retain their identity, within limits.
  - **1.** In order to explain, theories must contain assumptions that are not themselves deducible from empirical evidence.
  - **2.** This is consistent with central features of Kuhn’s model of science, but it simultaneously provokes challenges to that model.

Recommended Reading:

Imre Lakatos and Alan Musgrave, *Criticism and the Growth of Knowledge.*

Dennis Overbye, *Lonely Hearts of the Cosmos.*

Questions to Consider:

1. Are such concepts as cause, effect, space, time, position, velocity, matter, energy, species, and genus means by which we organize experience, or do they name features of reality?
2. Why do some clearly gifted people become outsiders to communities that they try hard to belong to? Why, once it is clear they are outsiders, do they keep trying to become insiders?

Lecture Nineteen

Objectivity Under Attack

Scope: Kuhn's *Structure* was enthusiastically embraced by social scientists, historians, literary theorists, and some philosophers of science, who saw in it a legitimation of a generic critique of objectivity to which they were sympathetic. Opposing the rush to expose scientific knowledge as "socially constructed," historical, value-laden, and ideological, Israel Scheffler harshly criticized the Kuhn-Polanyi-Hanson critique of science. Scheffler cited the social, political, and cultural, no less than the intellectual, price to be paid for debunking objectivity and especially for undermining the privileged status of scientific knowledge. Paul Feyerabend, however, was a philosopher of science who embraced exactly the position that Scheffler condemned, deriding the concept of a method of scientific discovery and arguing for pluralistic conceptions of knowledge, truth, and reality. Meanwhile, the work of primarily French intellectuals, notably Michel Foucault and Jacques Derrida, argued that all claims to knowledge and authority were fundamentally rhetorical, that they reflected contingent interpretations of experience—and of texts—based on evolving social, cultural, and personal value judgments. Foucault's historicized structuralist theory of knowledge and Derrida's deconstructionist theory of meaning anchored the rise of postmodernism.

Outline

I. As the *Structure* bandwagon grew in the 1960s, Harvard University Professor Israel Scheffler recognized the destructive implications of the analyses of scientific knowledge by Kuhn, Polanyi, and Hanson.

- **A.** Scheffler used a series of lectures at Oberlin College in 1965, published as the book *Science and Subjectivity*, as a platform for responding to what he saw as a threat to the foundations of Western intellectualism and to progressive social values.
  - **1.** The ideal of objectivity is fundamental not only to science but also to what we in the West have historically meant by rationality.
  - **2.** This ideal is the basis of all attempts at formulating compelling but noncoercive assent to shared values, shared social values no less than shared intellectual truths.
  - **3.** To call objectivity into question is, thus, to legitimate subjective beliefs, dogma, factionalism, and parochialism as the ultimate basis of social and intellectual community, reinforcing the worst features of human nature.
  - **4.** By contrast, classical conceptions of knowledge, reason, truth, and objectivity inspired the pursuit of universal forms of community that promised to overcome the worst features of human nature.
- **B.** Scheffler defended precisely the "image of science by which we are possessed" that Kuhn argued against in *Structure.*
  - **1.** Scheffler defended science as a "systematic public enterprise" controlled by logic and empirical fact, against the claim that data are "manufactured" by theory.
  - **2.** The purpose of science, Scheffler argued, is to formulate "the truth" about the natural world as universal laws of nature, not to invent realities that are merely predictively successful imaginative projections of scientific thought.
  - **3.** An underlying constancy of logic and method lends unity to the historical sequence of scientific theories and, thus, allows objective evaluation of proposed new theories. He rejected the claim that theory change is a matter of intuition, persuasion, and conversion.
- **C.** For Scheffler, the Kuhn-Polanyi-Hanson critique of science calls into question whether science is a "responsible enterprise of reasonable men."
  - **1.** At stake is the moral import of science: the example it sets of the power of reason applied to experience and of how to be reasonable.
  - **2.** If we give up the notions of a fixed observational given, the constancy of the descriptive language of science, and its methodology of investigation, science ceases to be a rational community advancing our knowledge of the real world.

3. If, to use the language of Logical Positivism, observation statements and concepts/theory statements are not strictly separable, then there is no independent control over individual thought, and anarchy follows in which might makes right!

II. If Scheffler was at the right wing of the spectrum of responses to the Kuhn-Polanyi-Hanson reassessment of scientific knowledge, Paul Feyerabend seemed to be at the far left wing.

A. Feyerabend came late to philosophy of science, after advanced training in music and then service in the German army during World War II.

1. In the 1950s, Feyerabend became interested in the rigorous, logico-mathematical analysis of scientific reasoning practiced by the remnants of the Vienna Circle of Logical Positivists.

2. Through them, he encountered Karl Popper, who was then a professor at the London School of Economics.

3. He became a student of Popper's and initially defended Popper's interpretation of scientific knowledge but soon became increasingly heretical.

B. Feyerabend enthusiastically accepted characterization as an irrationalist.

1. Feyerabend began, so to speak, where Kuhn and Hanson left off: proclaiming that science does not proceed rationally.

2. Rationalism, he wrote, was not the "last and only word" in matters relating to knowledge.

3. In his 1975 book *Against Method*, Feyerabend denied that there was such a thing as the scientific method and argued that major scientific advances were the result of irrational "moves," both at the level of discovery and of justification.

C. Feyerabend was, however, not as radical as he seemed, nor did he merit the outrage he provoked from scientists and defenders of the objectivity of scientific knowledge. He was *not* Scheffler's worst fear realized.

1. The rationality Feyerabend rejected was the rationality of classical philosophy.

2. It was the process of discovery that Feyerabend considered methodologically anarchical, not the process of justification.

3. That there was no single, logico-experimental method employed by all scientists, even by all physicists, was commonly accepted by 1975.

4. Feyerabend defended a relativist and historicist form of rationality that accepted ambiguity and contradiction as inescapable features of reasoning, that is, a form of rationality very similar to that championed by the Sophist rivals of Plato and their moderate skeptical heirs.

III. Quite independently of the 1960s critique of scientific knowledge, a group of French philosophers, among them Michel Foucault and Jacques Derrida, launched an attack on the foundations of the classical conception of rationality and on the very possibility of objective knowledge.

A. Foucault "excavated" the social history of ideas as an archaeologist opens a dig.

1. Foucault employed an archaeological-excavational method and a genealogical method to expose the cultural rootedness of the concepts we use to organize and make knowledge and value claims about our experiences and to trace the course of the changes of these concepts and correlated claims over time.

2. He applied this method to Western conceptualizations and institutionalizations of madness, criminality, and sexuality and to the conception of objective knowledge, especially the dominant valuation of necessity over contingency.

3. Equally critical of subjectivity, Foucault sought a method that could recover shared meanings and a historicist notion of truth from contingent, evolving experience.

B. Jacques Derrida, early a collaborator of Foucault's but later bitterly dismissed by him, invented a method he called "deconstruction" that posed the most fundamental challenge possible to the dominant Western conceptions of rationality, objectivity, truth, and knowledge.

1. Extending Swiss linguist Ferdinand de Saussure's theory of language as a closed system of differences, Derrida argued that meaning was intrinsically, inescapably equivocal.

   2. **2.** Attributing a fixed meaning to any thing—a text, a building, nature—is an unrealizable ideal, typically a rhetorical ploy aimed at controlling responses to things/events.
   3. **3.** Authors quixotically attempt to impose a meaning on their texts, but it is in the nature of writing, in the nature of language, that fixity of meaning escapes both authors and readers: Meaning is constructed through evolving processes of interpretation and reinterpretation.

- **C.** Derrida generalized the notion of "text," thereby extending the scope of deconstruction as a means of exposing implicit meanings and values.
   - **1.** In this sense, automobiles are "texts" to be "read" by uncovering the messages they are designed to convey to owners and others; and buildings are "texts" as well.
   - **2.** Foucault and Derrida championed hermeneutics, interpretation, as a methodology, in explicit opposition to the Cartesian method of analysis that dominates mainstream Western philosophy and modern science.
   - **3.** The movement they initiated extended the critique of objectivity and of objective knowledge far beyond what Kuhn's *Structure* implied, leading to a radical critique of science.

Recommended Reading:

Alan Sheridan, *Michel Foucault: The Will to Truth.*

Rodolphe Gasche, *Inventions of Difference: On Jacques Derrida.*

Questions to Consider:

1. Is social community threatened by the claim that objectivity is an intellectual abstraction only?
2. By what standard do we judge that one interpretation of *Moby Dick*, say, is superior to another? Would the presence of the author help, or would it reveal that he himself was not conscious of the multiple meanings that could be read into his complex novel?

Lecture Twenty

Scientific Knowledge as Social Construct

Scope: In the 1980s, a consensus formed that scientific and technological knowledge were not value-neutral, but the products of communal practices deeply affected by professional and societal values. Early sociology of science had restricted itself to studying the organization of scientific research and scientific communities, accepting the content of science as objective. In the wake of Kuhn and Hanson, the Foucault- and Derrida-led critique of objectivity and rationality, and the pervasive antiestablishment political mood of the 1960s and 1970s, the scope of sociology of science widened. Sociologists, especially in Great Britain, the United States, and France, argued that the content of science was actively constructed by scientific communities. In the traditional, "archaeological" view of science, it was nature, through facts collected by observation and experiment, that validated scientific theories. On the constructionist view, scientific theories are produced by professional thought collectives whose members employ a shared set of assumptions, principles, methodologies, practices, *and values* to construct interpretations acceptable to them of intrinsically equivocal empirical data. Scientific truth, thus, is produced by scientists, not by nature, which implies that science is just another social practice, privileged only through its association with institutions of social and political power.

Outline

I. Independent of Kuhn, Jerome Ravetz's *Scientific Knowledge and Its Social Problems* (1971) depicted science as a distinctive *craft* activity, one that created and solved problems associated with natural phenomena.

- **A.** By calling science a craft, Ravetz entangled science with its social context, made it a social practice, as much influenced by, as influencing, that context.
  - **1.** From the inside, science is all about nature. From the outside, we can see that what goes on inside science depends on social, political, financial, and moral, as well as intellectual, inputs from society, and its outputs have much more than intellectual consequences for society.
  - **2.** Scientists *create* the problems they try to solve; they don't just find them, and in the process, science also creates problems for society.
  - **3.** Ravetz concluded that technical knowledge, whether science or engineering, was *not* value-neutral.
- **B.** By the end of the 1960s, it was apparent that the science-technology-society (STS) relationship was of growing significance to society.
  - **1.** The popular model of the STS relationship was that "pure" research generates "pure," application-neutral, objective knowledge.
  - **2.** The choice of application is independent of science, whose job it is to give a "true" account of what things "really" are and how they work.
  - **3.** If society is unhappy with technological applications of scientific knowledge, the point at which to intervene is "downstream" from science, because knowledge is independent of its application.
- **C.** The insulation of science from negative social consequences of technology broke down in the 1960s. One response was political action; another was scholarly study of the STS relationship.
  - **1.** STS studies began with an IBM-funded research project at MIT and academic programs at Cornell, Lehigh, and Pennsylvania State universities, and spread nationally and internationally.
  - **2.** Academic STS programs were a *symptom* whose cause was growing social concern with, and growing intellectual interest in, the relationships among social institutions, the knowledge scientists generated, and technological innovation.
  - **3.** Concurrently these programs played a causal role, creating a broad community of scholars, writers, social critics, scientists, and engineers committed to exploring the STS relationship.

II. STS studies provided the context within which a group of social scientists began to argue that scientific knowledge was socially constructed.

- **A.** Sociology of knowledge theorists in the 1930s excluded scientific and mathematical knowledge from the scope of their study but included the organization and social structure of scientific research communities.
  - **1.** Beginning in the early 1970s, a growing number of sociologists began applying sociological and anthropological research methods to the content, as well as the conduct, of science.
  - **2.** An explosion of articles and books made (natural) science itself the subject of (social) scientific study without segregating content and conduct.
- **B.** Steve Woolgar and Bruno Latour's 1979 *Laboratory Life* summarized the results of one anthropological approach to studying the internal workings of the production of scientific knowledge.
  - **1.** The authors spent most of two years as observers in the Salk Institute laboratory of Roger Guillemin, who was subsequently awarded the Nobel Prize in medicine for isolating throtropin-releasing factor in this laboratory.
  - **2.** Like anthropologists studying an unknown tribe, they recorded all the activities of scientists and technicians: conversations and gossip; calibration and operation of equipment; design and execution of experiments; analysis and interpretation of data; monitoring of the activities of colleagues and rivals; and preparation of materials for grants, publication, and conference presentations.
  - **3.** What emerged was a new kind of account of the complex social and intellectual processes underlying what Woolgar and Latour present as the *creation*, rather than the *discovery*, of a new "piece" of scientific knowledge.
- **C.** Karin Knorr-Cetina's 1981 *The Manufacture of Knowledge: An Essay on the Constructivist and Contextual Nature of Science* asserted the new scope of the sociology of scientific knowledge, as did a seminal 1983 volume she co-edited, *Science Observed: Perspectives on the Social Study of Science.*
  - **1.** The language of "construction," with its connotations of contingency, interpretation, and deliberate choice, became the buzzword of the new approach.
  - **2.** Laboratories are socially constructed, instruments and experiments are socially constructed, and data and theories are socially constructed: It follows that knowledge is socially constructed!
  - **3.** Those practicing, or convinced by, the new sociology of science seemed to take a certain glee in what working scientists witnessed with dismay: the disappearance of nature from scientific knowledge, along with evidence, facts, and logic as controlling scientific truth claims.

III. Throughout the 1980s and after, numerous studies of contemporary natural scientific practice were published arguing that, whatever nature was, metaphysically, what scientists meant by *nature* was constructed by the scientific community—hence social.

- **A.** Harry Collins's 1985 *Changing Order*, and its 2005 sequel *Gravity's Shadow*, illustrate one approach to arguing the constructed character of scientific knowledge.
  - **1.** Replication of results is fundamental to validating scientific knowledge claims, and *Changing Order* begins by exposing the complexity of replicating in one laboratory the results announced by another; here, the issue was replicating a new kind of laser.
  - **2.** Collins then examines problems posed by data from new types of instruments, using as an example a gravity wave detector built by a highly respected physicist, who announced that it had successfully detected such waves for the first time. His results were dismissed by the physics community.
  - **3.** *Gravity's Shadow* describes the impact of that dismissal on the physicist's life and career, and contrasts it to the response of the same community to a new generation of detectors constructed c. 2000.
  - **4.** Finally, *Changing Orde*r examines the rejection by the science community of ostensibly experiment-based knowledge claims involving research into the paranormal as pseudo-science.
- **B.** Andrew Pickering's *Constructing Quarks* (1984) was perhaps the benchmark study for claiming the social construction of knowledge in physics.

   1. To the consternation of many in the physics community, Pickering claimed to expose the role played by contingent judgments in the reasoning behind the formulation and acceptance of the quark theory of matter.
   2. In the context of a technically correct history of post–World War II elementary particle physics, Pickering argued that experimental reports are intrinsically fallible, dependent on theories of how instruments work, of what is dismissible “noise” and what is a meaningful signal, and on interpretations of what their output means.
   3. At every stage of doing science, judgments need to be made that cannot be derived from data or from logical considerations alone and that can only be said to “work” if they are acknowledged as legitimate by peers.

C. Stepping back from the accumulating body of case studies, Bruno Latour, in his 1987 book *Science in Action*, offered a deliberately provocative summation of the case for the so-called “strong program” in sociology of science: that scientific knowledge is socially constructed.

   1. Science, Latour wrote, refers not to a body of objective knowledge but to all of the activities in which scientists engage, including recruiting allies to their research methods and results and organizing those allies into networks.
   2. Statements about nature, and statements about the results of experiments, are only meaningful within chosen networks of people, instruments, and texts. It follows that rationality and objectivity are social constructs.
   3. Nature is what scientists say it is, and its constituents are the laboratory behaviors to which scientists give names. It follows that nature, in the realist sense, plays at best a minor role in deciding scientific controversies!

Recommended Reading:

Ian Hacking, *The Social Construction of What?*

Helen Longino, *Science as Social Knowledge.*

Steve Woolgar and Bruno Latour, *Laboratory Life.*

Questions to Consider:

1. Is the claimed objectivity of scientific knowledge compromised by the manifest dependence of scientific research communities on social, political, and commercial institutions for support?
2. If, as so many historical, philosophical, and sociological case studies strongly suggest, scientific knowledge is in some significant sense socially constructed, does it lose its claim to objectivity?

Lecture Twenty-One

New Definitions of Objectivity

Scope: Empirical experience is mute without a language in which we can say what is “out there,” causing experience to be as it is and as it will be. Such a language would enable explanation, prediction, and control, but where could its names, concepts, and definitions come from: nature, thus giving science its objectivity, or scientists, making scientific knowledge conventional? Philosophers, too, need a descriptive vocabulary, for example, to talk about science. Where do *their* definitions come from? These questions are troubling only if we are realists, insisting that science discloses reality. But science as practiced *is* realist, and science *works*, in spite of the fact that its realism is admitted to be profoundly problematic. Kuhn, Hanson, and Feyerabend didn’t invent a crisis for science. They exacerbated one that had been evaded for centuries. Still, few philosophers, and fewer scientists, were prepared to embrace the relativism that seemed the only alternative to realism. While many intellectuals after 1960 were busily denouncing Western ideals of rationality, knowledge, and truth as politically motivated myths, many philosophers of science proposed critically defensible theories of scientific realism.

Outline

I. Realism is woven into the fabric of natural science, into its rhetoric and its practice.

- **A.** Taken at face value, the language of scientific theories describes what nature is made of, how it is constituted, and how it works, as if the terms of those theories corresponded to objects in nature and relationships within theories corresponded to processes in nature.
  - **1.** The critique of this overt objectivism and realism is first of all a critique of the term “knowledge,” not a rejection of the efficacy of scientific theories.
  - **2.** Kuhn, and others, extended this critique of what “knowledge” means to what we are to understand by “objective” and “universal.”
  - **3.** The issues raised by these critiques are all implicit in Fourier’s move and became explicit long before Kuhn.
- **B.** Kuhn triggered a confrontation with realism that had been latent in modern science from the beginning.
  - **1.** Galileo’s conflict with the Catholic Church, for example, was over his insistence that the Copernican theory described astronomical reality.
  - **2.** The issues raised by the post-WWII critiques of knowledge, objectivity, universality, reality in the context of scientific knowledge claims were all implicit in Fourier’s move and had become explicit by the end of the 19th century.
  - **3.** Note that being socially constructed does not mean that something is not real!

II. Three approaches to defending objectivity are of special interest: the covering-law model of scientific explanation, naturalized epistemology, and evolutionary epistemology.

- **A.** Carl Hempel was a member of the Logical Positivist (LP) movement and, having emigrated to the United States, attempted to rescue LP’s original program from the failure.
  - **1.** In 1948, Hempel (and his longtime collaborator Paul Oppenheim) argued that the logical structure of scientific explanation was deductive: theory premises were one or more laws of nature, which might be probabilistic, as in quantum mechanics, along with a relevant set of boundary conditions, while the conclusion was the phenomenon to be explained.
  - **2.** Hempel replaced LP’s separation of theory and observation statements with Internal Principles and Bridge Principles as the elements of his theory of explanation.
  - **3.** Note the identity of explanation and prediction, the absence of any reference to causality, and the striking similarity to Descartes’ deductive methodology of “feigning” hypotheses.
- **B.** W. V. O. Quine played a key role in undermining LP, but he promoted an approach to validating science as a realist enterprise called naturalized epistemology.

    1. **1.** Quine argued that the study of how we know was properly a scientific project, not a philosophic one; thus, epistemology, at least that branch of it that studied how the mind-brain reasons about its sensory experience, is a branch of psychology.
    2. **2.** He later softened this position to one in which knowing how the mind-brain functions in reasoning about "nature" is a necessary but not a sufficient condition to understanding what we can know and how we know it.
    3. **3.** By 2000, cognitive neuroscience was providing the knowledge Quine had called for, but what were we to make of *that* body of knowledge as a theory of scientific knowledge?

  - **C.** Evolutionary epistemologists have argued that the "fit" between nature and successful ideas about nature was guaranteed by our evolutionary history.
    - **1.** The social psychologist Donald Campbell championed evolutionary epistemology, seeing it as a bulwark against epistemological and ontological nihilism.
    - **2.** Campbell defended a radical analogy between biological evolutionary theory and science, arguing that scientific reasoning proceeded by blind variation and selective retention.
    - **3.** More convincing were Campbell's arguments that scientific knowledge was, on evolutionary grounds, capable of being realist and objective while at the same time being always corrigible. Knowledge becomes "fitter" as it becomes better adapted to evolving experience.

- **III.** Very few philosophers of science defend "radical" skepticism/relativism, but even fewer agree that science can give us universal, necessary, and certain knowledge of nature. The variety of attempts to justify scientific knowledge as realist and objective, *in some sense*, testifies that the problem is still alive and well!
  - **A.** Hilary Putnam, Nelson Goodman, Ronald Giere, and Philip Kitcher offered theories of scientific knowledge that illustrate core features of neo-objectivism.
    - **1.** Putnam argued that the object of science is indeed the world out there, independent of our thinking, but that how we organize our experience of that world is determined by the concepts scientists choose to employ.
    - **2.** This is, of course, reminiscent of Fleck's "active relations" and of Nelson Goodman's argument, in his book *Ways of Worldmaking*, that what we mean by "the world" can only be defined relative to a deliberately chosen framework: We encounter reality only through descriptions of it.
    - **3.** Giere argues that scientific theories are models, not revelations, of laws of nature.
    - **4.** Kitcher strongly defends a form of realism that acknowledges that the demand for certainty cannot be met and that no "fundamental" justification of knowledge of nature is possible. His "mapping" metaphor for science is similar to Putnam's internal realism and to Goodman's frameworks.
  - **B.** Other approaches to rescuing the objectivity of scientific knowledge are to be found in the work of Arthur Fine, Bas van Fraassen, and Imre Lakatos.
    - **1.** Arthur Fine's natural ontological attitude (Kitcher refers to a natural epistemological attitude) is a systematic, empirically checked extension of common sense, supporting a nondogmatic realism that dispenses with the notion of absolute truth and in which scientific knowledge, mirroring experience, is open-ended.
    - **2.** The eminent Dutch-Canadian philosopher of science Bas van Fraassen has argued that ontological claims for theoretical scientific objects add nothing to their explanatory power or to the predictive success of the theory and, thus, are vacuous.
    - **3.** Imre Lakatos argued that the fertility of the research programs provoked by a theory that made novel predictions are the grounds of a theory's acceptance as true.

Recommended Reading:

Nelson Goodman, *Ways of Worldmaking*, chapter 1.

Larry Laudan, *Science and Relativism.*

Questions to Consider:

1. Given humanity's biological success in populating the Earth and transforming it, how can our ideas about the world not correspond to what is out there?
2. What's the difference between the metaphors of mapping the world (Kitcher, among others) and modeling it (Giere)?

Lecture Twenty-Two

Science Wars of the Late 20th Century

Scope: By the end of the 1980s, what had begun as a scholarly reassessment of the status of scientific knowledge claims and identification of the processes in and through which scientific knowledge is generated had become a debunking of scientific knowledge. Universality, objectivity, and value-neutrality were, it was claimed, powerfully entrenched cultural myths, and so were knowledge and rationality. Initially, the natural science community largely ignored these attacks or dismissed them as too irrational to be worth commenting on. But in the second half of the 1980s, a number of scientists joined the battle with social constructionist critics of scientific knowledge and with postmodernism. High points of the Science Wars that followed were the publication of *High Superstition* by the biologist Paul Gross and the mathematician Norman Leavitt, and the hoax perpetrated by physicist Alan Sokal on the postmodernist journal *Social Text*. This hoax triggered a global firefight among intellectuals across the disciplines. Concurrently, criticism of social constructionism on both intellectual and sociopolitical grounds dimmed the luster of postmodernism, but attacks on science continued, shifting from the intellectual left to the religious right.

Outline

I. In 1996, the "Science Wars" erupted officially, but that came after a decade of open hostility between natural scientists and supporters of the social construction of scientific knowledge.

- **A.** In the second half of the 1980s, members of the science community, which had largely ignored or dismissed social construction theory, began a counter-attack.
  - **1.** In 1986, the physicists Silvan Schweber and Yves Gingras published a review of Andrew Pickering's *Constructing Quarks* in the journal *Social Studies of Science.*
  - **2.** They chose a journal whose readership was very likely sympathetic to the depiction of social construction views of science.
  - **3.** They chose *Constructing Quarks* precisely because of the challenge it posed as a technically sophisticated book *in* physics *by* a physicist.
- **B.** Schweber and Gingras distinguished Pickering's history of post–World War II high-energy physics, which they praised, and his claim that quark theory was a social construct, which they rejected.
  - **1.** Pickering describes the social construction model around which his history is organized in the introduction, but, Schweber and Gingras argue, he tacitly employs that model in selecting which events to include in his history and how to depict them.
  - **2.** That selectivity affects the credibility of his conclusion regarding the primacy of theory to data and the centrality to scientific theorizing of nonlogical, contingent judgments imposed on data and validated by the assent of the community sharing those theory-based judgments.
  - **3.** Schweber and Gingras argue that data do indeed matter and that even for instruments explicitly constructed in accordance with a theory, experimental outcomes constrain that theory: Theory-based wishing will not make nature so!
- **C.** Concurrently, postmodernism, as the validating context of social construction views of knowledge, came under attack from within the broader academy.
  - **1.** University of Chicago political philosopher Alan Bloom's 1988 bestseller *The Closing of the American Mind*, lambasted postmodernism, arguing that liberal political philosophy has unleashed "anarchic relativism," undermining religion and traditional morality; has leveled all moral and intellectual values; and has justified an "anything goes" attitude in personal and social behavior.
  - **2.** E. D. Hirsch's 1987 bestseller *What Every American Needs to Know* attempted to identify the knowledge that, contrary to the postmodernists, defined Western cultural literacy and also identified the changes to the education system necessary to make cultural literacy the norm.
  - **3.** In Europe, the backlash against Foucault's and Derrida's ideas as ultimately elitist and anti-democratic found expression in Alain Renaut's 1989 *The Era of the Individual*, which argued that deconstruction of the self and of reason provided an intellectual justification of fascism.

II. One of the two high points of the Science Wars was the publication in 1994 of *Higher Superstition: The Academic Left and Its Quarrels with Science.*

- **A.** *Higher Superstition*, by Paul Gross and Norman Leavitt, was followed by *The Flight from Science and Reason* (1997), a collection of essays, written for a 1995 conference at the New York Academy of Sciences and organized in the aftermath of *Higher Superstition.*
  - **1.** In *Higher Superstition*, Gross and Leavitt focus on the left-wing humanist and social scientific critics of science.
  - **2.** They cite illustrations of the manifest ignorance of science of these critics and what is worse, their blatantly nonsensical misappropriation of science to support antiscientific claims.
  - **3.** They especially target postmodernist cultural constructivism, social construction of knowledge theory, feminist science criticism, and the radical environmentalist movement called *deep ecology.*
- **B.** Gross and Leavitt were appalled at the presence within the academy of so aggressive an attack on reason and on intellectual and social norms.
  - **1.** Gross and Leavitt were even more appalled at what they identified as the irrationality of the writings of these critics, the venom of their hostility to science, and their potential for doing serious damage to Western social institutions, including science.
  - **2.** *Higher Superstition* led to a conference at the New York Academy of Sciences in which dozens of philosophers, historians, and scientists participated. (Papers presented were published in book form as *The Flight from Reason and Science*.)
  - **3.** Prominent among them were feminist critics of so-called "feminist epistemology" and environmentalist critics of radical environmentalism, as well as defenders of traditional notions of truth, evidence, and the rationality of science.
- **C.** The second high point in the Science Wars was inspired by *Higher Superstition* and the response to it.
  - **1.** New York University physicist Alan Sokal submitted a paper—purporting to expose the socially constructed, ideology-based character of quantum gravity theory—to a special issue of the social constructionist journal *Social Text* that was called "Science Wars."
  - **2.** In fact, the paper was a tissue of physics nonsense cleverly lashed together with terminology that Sokal had extracted from a brief but intensive immersion in postmodernist literature.
  - **3.** He was, he said, feeding the editors what they wanted to hear as a test of their intellectual integrity, and they failed.

III. Sokal's hoax triggered a storm that raged through 1997, ranging from physicists proclaiming victory in the Science Wars to postmodernists expressing moral outrage at Sokal's "dishonesty."

- **A.** Sokal himself exposed what he had done in an article published in *Lingua Franca* immediately after his paper appeared in *Social Text*.
  - **1.** Sokal called his paper a "modest (though admittedly uncontrolled) experiment." Typically, natural scientists thought it fair; humanities faculty and social scientists thought it morally dubious, at best.
  - **2.** Steven Weinberg, Nobel Laureate physicist and champion of a classical objective-realist view of scientific knowledge, published a vigorous defense of the hoax and of the "obvious" conclusion: the intellectual (and moral?) bankruptcy of postmodernism.
  - **3.** Sokal went on to co-author, with the Belgian physicist Jean Bricmont, *Fashionable Nonsense*, which broadens and deepens the exposé of what he had parodied in the hoax: the prevalence in the works of leading postmodernists of what William James once called "nonsense writing," that is, writing that at first reading seems to make sense, but on closer reading turns out to make no sense at all.
- **B.** Curiously, some of the strongest defenses of the postmodernists came from the science community.
  - **1.** The Israeli historian of quantum theory, Mara Beller, published an article in *Physics Today*, in whose letters column many physicists had expressed glee at Sokal's hoax, citing numerous passages from works of the "hero" physicist founders of quantum theory that sounded just as much like gobbledygook as the passages by postmodernist writers that Sokal mocked.

2. Physicist David Mermin wrote a review of *Fashionable Nonsense* suggesting that Sokal and Bricmont had taken passages that they mocked as nonsense out of context; that in the context of a postmodern text these passages *did* make sense.
3. The storm, and the Science Wars, had dissipated by the end of the 1990s, in part because postmodernism seemed to have run its course: Once you've denounced every other position but your own and proclaimed the impossibility of a privileged position, you've pretty much painted yourself into a corner!

Recommended Reading:

Paul R. Gross and Norman Leavitt, *Higher Superstition.*

Ian Hacking, *The Social Construction of What?*

Questions to Consider:

1. For social constructionists, what's the point of doing anything about global warming?
2. Was Sokal's hoax justifiable? What if anything did it prove?

Lecture Twenty-Three

Intelligent Design and the Scope of Science

Scope: Militant postmodernism dissipated in the late 1990s and so did the political critique of science as co-opted by powerful special interests. Philosophers of science reemerged as overwhelmingly "friendly" critics of science, defending science as knowledge. The attack on science continued, however, but now from the religious right rather than from the liberal left. At a time when the intellectual and, especially, the scientific community had written religion off as a spent force, fundamentalism grew dramatically in numbers, influence, and assertiveness. The religious right focused its objections on theories and technologies that had implications for the origins, meaningfulness, and manipulation of human life. Darwinian evolutionary theory was the primary target, and the demand was either for evolution to be dropped from biology curricula as an unproven, even false, theory or for the biblical creation account to be included. *McLean v. Arkansas* slowed the creationist challenge, which shifted to a demand that intelligent design be taught alongside evolution as a rival scientific hypothesis. The controversy that followed highlighted the questions: Who defines what science is, what "good" science is, and what such words as *rationality*, *truth*, *knowledge*, and *reality* mean?

Outline

I. The rejection by the courts of inclusion of creationism in the high school biology curriculum as an alternative to evolution was followed by attempts to include Intelligent Design as an alternative, on the grounds that Intelligent Design is a scientific hypothesis, not a religious doctrine.

  A. One question this raises is the determination of whether any proposed hypothesis is a scientific hypothesis.

    1. Unfortunately, there is no *Official User's Guide to Reality* to which we can turn for the definitive determination of whether a given hypothesis is scientific.

    2. The same holds true for the determination of what such key terms as *rationality*, *truth*, *knowledge*, and *reality* mean and/or refer to.

    3. In the end, it is, and can only be, the community of scientists who determine if a hypothesis that claims to be scientific is accepted as such.

  B. What are the criteria that the science community uses in accepting or rejecting a proposed hypothesis as a scientific hypothesis?

    1. One lesson from the history of the term *knowledge of nature* is that there is no ironclad methodological rule in science.

    2. Explanatory power, logical consistency within a given set of assumptions, correlation with present experience, and especially correlation of the logical consequences of a theory with predicted future experiences are critical.

    3. Testability and falsifiability are sufficient to qualify a hypothesis as scientific but not necessary in the short run if a proposed hypothesis or theory is attractive on explanatory grounds and is fertile in stimulating new lines of research (which promise testability and falsifiability in the long run).

  C. Where does intelligent design stand as a hypothesis?

    1. First of all, intelligent design violates one of the foundational rules of science as a disciplined approach to the study of nature: For science, nature must be treated as a closed system. A scientific explanation of a natural phenomenon cannot invoke a supernatural causal agent.

    2. Without access to the designer or a copy of the original design, intelligent design does not make a difference operationally. It is not fertile in terms of research programs, it does not make predictions that follow only from intelligent design, and it seems not to be testable or falsifiable.

    3. Intelligent design addresses a legitimately scientific *problem*, namely, the manifest *appearance* of design in natural phenomena, but it does not so much explain design as explain it away.

II. Fundamental support for intelligent design as a scientific hypothesis comes from the claim that Darwinian evolution is, at best, a flawed scientific theory, an unproven speculation not confirmed by empirical evidence.

- **A.** A pillar of the intelligent design position is biologist Michael Behe's book *Darwin's Black Box.*
  - **1.** Behe argues that intelligent design must be at least considered true because Darwinian evolution cannot explain the existence of the complex biochemical systems characteristic of life forms.
  - **2.** A system, Behe claims, can only come into existence from the top down, so to speak, because its parts are mutually adapted.
  - **3.** Darwin's theory is a bottom up explanation of the spontaneous emergence of new life forms, and so it cannot explain the emergence of systems.
  - **4.** For Behe, it follows that with the failure of Darwinian evolution we must turn to intelligent design, which can explain the emergence of systems.
- **B**. Behe's argument seems to me deeply flawed on at least three grounds.
  - **1.** It employs a form of reasoning recognized as fallacious even in ancient Greece, namely, the argument from ignorance**:** to say that theory X cannot explain phenomenon Y provides no support whatsoever for the claim that some other theory Z is true!
  - **2.** The community of biological scientists continues to work with evolutionary theory, and the theory continues to evolve, as all "good" scientific theories do.
  - **3.** A new science of self-organizing systems has grown since the 1970s that is a more promising scientific basis for explaining the emergence of complex biological systems than jumping to a supernatural "intelligent designer" hypothesis.
  - **4.** Furthermore, there is evidence that complex socio-technical systems have in fact emerged from the bottom up.
- **C.** But at a deeper level, the attempts to discredit evolution as a scientific theory reflect a misunderstanding of the nature of scientific theories and of scientific knowledge.
  - **1.** Evolutionary biology today is not synonymous with what intelligent design supporters call Darwinian evolutionary theory, just as contemporary astronomical theory is not synonymous with Copernican astronomy, nor is the current Big-Bang-with-Inflation theory of the Universe synonymous with George Gamow's original theory.
  - **2.** Theories evolve over time, and all major theories—what Kuhn meant by paradigms, of which evolutionary theory is an instance—evolve multidimensionally, becoming integrated into an expanding explanatory web driven by correlated research programs.
  - **3.** Darwinian evolution displays precisely this characteristic, with its evolving correlation with genetic theory, molecular biology, anthropology, ecology, environmental science, and plate tectonic geology.

III. The case, from the side of the history and philosophy of science, against the claims that intelligent design is a scientific hypothesis and that evolutionary theory is flawed/false is vastly stronger than the case that these claims are true. So how did we get to this point?

- **A.** First and foremost, intelligent design is both an intelligent and a reasonable hypothesis, with an outstanding intellectual "pedigree."
  - **1.** From Aristotle right through the mid-19th century, many of the leading philosophical and scientific thinkers in the Western cultural tradition accepted the appearance of design in nature as a sign of a reality *behind* nature.
  - **2.** Not a single one of these thinkers, however, including many eminent scientists, considered design as a scientific hypothesis: It justified their belief in a supernatural or supra-natural designer (for Aristotle, a supra-natural nondesigner).
  - **3.** Parallel to this mainstream tradition and beginning long before Aristotle was a line of thinkers who argued that design in nature was only apparent and that nature was the product of chance and the operation of forces within nature.
- **B.** Why has the religious right singled out evolutionary theory, rather than quantum theory, for example?
  - **1.** Darwinian evolution, as the right formulates it, directly undermines every traditional conception of the meaningfulness of human existence.

    2. If we take Darwinian evolutionary theory as true, as knowledge of reality, then human life is no more meaningful than a bacterium's life.

- C. The intelligent design controversy is yet another collision between religious belief and intellectual inquiry claims to exclusive truth, reflecting a misconstrual on both sides of the nature of scientific knowledge.
    1. By definition, religious belief is not wholly rational, and the historical record is unequivocal that the attempt to impose religious truth on society has catastrophic consequences.
    2. The historical record is equally unequivocal that scientific knowledge is a continually evolving, contingent, hypothetical, and corrigible product of a process keyed to theoretical assumptions—provoked by but not logically derivable from empirical experience—that are constantly tested against and validated by their ability to explain, predict, and control experience.
    3. The defensiveness of the scientific community's response, first to the social constructionists, then to the postmodernists, and now to the intelligent design assault, has obscured what we have learned about the historicity of scientific knowledge: that no theory can be a fact and that, in the absence of an absolute authority, only the scientific community can say what it will call scientific knowledge.

Recommended Reading:

Michael Behe, *Darwin's Black Box.*

Questions to Consider:

1. What caused the astonishing revival of fundamentalist religious affiliation, not only in Christianity, but also in Judaism and Islam?
2. Why did American but not European Christianity experience this revival, while the experience of Judaism and Islam was global?

Lecture Twenty-Four
Truth, History, and Citizenship

Scope: The "stories" about nature, and fantastic-sounding stories at that, that scientists tell us about the world are required by the rules of scientific inquiry to map onto actual experiences. The theories are as true as that mapping is explanatorily and predictively fertile. Fertility is the only criterion we have to any relationship between actual experience directly and the unexperienceable reality that is postulated as its cause and the ultimate referent of scientific knowledge. Because experience is continually changing, so, too, must theories and the testing of their mapping. What cumulates in all this change is fertility, and it is this cumulation that many *interpret* as the progressive convergence of science to reality. What scientific knowledge cannot offer us, however, is certainty that our accounts of experience correspond to the real. This gulf is the cause of the 2,400-year-long "war" in Western culture between competing conceptions of rationality: universal-necessary versus instrumental-pragmatic. At a time when science is implicated in profound social, moral, and environmental challenges to future human well-being, misunderstanding the positions of competing interpretations of science is an obstacle to rational action in response to those challenges.

Outline

I. We've come a long way, chronologically but also conceptually, in exposing the complexity of the methodological "how" behind scientific knowledge claims.

  A. The historicity of scientific knowledge emerges as central to any assessment of scientific knowledge claims.

    1. Science is continually changing: at the level of data, as more sensitive experimental instruments and techniques are developed, as new kinds of instruments and techniques are invented, and as new analytical tools are created; at the level of interpretation of data; and at the level of theory.

    2. The rate of change varies, but contrasting what scientists claimed to know in 2000 with what they claimed to know in 1900, contrasting "reality" in 2000 with "reality" in 1900, is a revelation.

    3. As Mary Hesse cautioned, the lesson of the historicity of science is that the theories we currently hold to be true are as falsifiable as the theories they replaced!

  B. That what scientists know is influenced by how they produce knowledge is revealed to be a consequence of the *constructed* character of scientific knowledge.

    1. Many eminent scientists, from the early 19th through the mid-20th centuries, recognized that scientific theories necessarily employ assumptions that cannot be deduced from experience.

    2. These assumptions are what allow us to *construe* what we extract from experience and label *scientific* data as evidence for causal explanations and theories that are then validated by "nature" through past, present, and future experiences.

    3. This process reveals the extent to which science is a collective enterprise in which individuals participate, constrained by professional and intellectual rules that structure the individual's encounter with "reality."

    4. As a collective enterprise, scientists employ a shared language to describe the phenomena they study and to formulate explanations of them, but it is at best an open question whether they invent the language(s) they employ or learn the "language" of nature.

  C. In addition to the historicity of scientific knowledge, and the dialectic of individual and collective in responding to experience "scientifically," we have also exposed the historicity of the term *knowledge.*

    1. The recent Science Wars were only a skirmish in a 2,400-year-long battle over what rationality, truth, and knowledge are and what they refer to.

    2. If they refer to experience, then rationality, truth, and knowledge are probable, contingent, and particular; context-dependent; and historical.

    3. If they refer to reality, they are necessary, certain, and universal, hence context-independent and timeless.

    4. From the start, modern science has been conflicted about its referent, identifying its method as empirical (hence experiential), while allying itself with Rationalism by emphasizing deductive reasoning and claiming that its experimental method could penetrate experience to reality.
    5. Experience is itself the source of the persistent ambivalence of practitioners of science as to the object and nature of scientific knowledge and truth claims.

II. John Dewey's conception of experience suggests why science is ambivalent about knowledge and points a way to overcoming it.

- **A.** A stumbling block in attempting to understand science as a process of inquiry *and* as knowledge, in the strict sense, is the defensiveness of scientists on the subject of the relationship of science to reality.
    1. The term *reality* is so freighted with connotations and values that it is preferable to say that the object of scientific knowledge is neither experience nor reality but *actualities*—scientific objects, such as the Sun, the Earth, atoms, genes, black holes—all inductively inferred from experience.
    2. Scientific theories can be understood as mapping, not onto some ultimate and inexperienceable Reality, but onto such actualities, which are rooted in empirical experiences, current or potential, directly or indirectly, via instruments, all defined by the scientific community.
    3. The mapping criteria always link actualities to experience and allow us to check the correspondence of claims about the behavior and properties of actualities with experience.
    4. Note that instruments used to produce experiences that validate actualities are themselves the products of the thinking associated with identifying actualities.
- **B.** Actualities invariably re-describe and displace ordinary experience.
    1. Copernican astronomical theory is a case in point, as is the expanding Universe theory, the atomic theory of matter, and quantum field theory.
    2. Ask a scientist what is real and the answer will be particles and fields, forces and structures (mathematical and physical), genes and molecular assembly plants, that is, actualities defined by science.
    3. Redefining actualities is less threatening than redefining Reality and the check of correspondence with new experiences reinforces our conviction that these objects defined by the scientific community are "real," in a sense we can justify pragmatically.

III. The relationship between scientific actualities and ordinary experience is less contentious than the relationship between actualities and reality, and that can clarify science's role in public policy debates.

- **A.** Discovering "the truth" about experience, discovering truths about what has not yet been experienced, is what science is all about, but is science the only source of truth about experience?
    1. The short answer *must* be no, if only because there is no single, natural definition of *truth.*
    2. Science is *a* source of truth about experience, and it is the only source of truth about actualities that become "real" within a process of inquiry that defines "rationality" for science.
    3. For scientists, the relationship between ordinary experience and their displacing explanations of it via actualities is not problematic because actualities are more real to scientists than ordinary experience.
    4. For nonscientists, however, the relationship is opaque and can only be clarified by taking the scientists' word for it or by learning the science involved, in effect, by joining "them."
- **B.** As with knowledge, the truths arrived at by scientists are also a function of the assumptions and principles they adopt and the modes of data analysis and interpretation they employ.
    1. Like scientific knowledge, then, scientific truths have a hypothetical, contingent, and corrigible character. Truth claims, too, are fallible and temporal.
    2. These characteristics of scientific knowledge and truth are belied by the deductive logical form in which theories are formulated, taking as givens the assumptions and principles they incorporate.
    3. As a result, predictions about experience appear as logically necessary consequences of a theory, *as if* the theory corresponded to reality rather than to internal-to-science actualities.
- **C.** What scientific knowledge is knowledge of becomes of practical concern to the general public when it turns to scientific knowledge to resolve public policy issues "objectively."

1. Scientific knowledge can never achieve certainty about “reality,” and so scientists cannot tell us with certainty why the present is as it is and how the future will be.
2. Faced with decisions, we must choose without the kind of knowledge that would allow us to deduce the one “correct” choice.
3. The ethos of modern scientific practice, and the form in which scientific knowledge is cast, explicitly exclude value judgments from the purview of science, so that scientists, *as scientists*, cannot prioritize courses of action.
4. That science cannot tell us what to do opens a space in a democratic society for the general public to participate even in the most technical policy debates—uses of the human genome database, global warming, nuclear energy, cloning, nanotechnology applications—and it places responsibility and accountability for policy choices on the public and its representatives.

Recommended Reading:

Mary Hesse, *Revolution and Reconstruction in the Philosophy of Science.*

Philip Kitcher, *Science, Truth and Democracy.*

Questions to Consider:

1. How can the members of a democratic society collectively determine what choices will advance the general interest?
2. What level of science literacy is necessary for the public to play an informed role in science and technology policy issues that directly affect public welfare?

Timeline

1543	Publication of Nicolas Copernicus's *On the Revolution of the Heavenly Spheres*
1565	Council of Trent: Catholic Church maps counterattack against the spread of Protestantism
1572	Tycho Brahe observes nova and locates it in the supposedly changeless heavens
1577	Brahe observes comet and shows that its orbit slices through the heavenly spheres
1596	Johannes Kepler publishes mystical-Copernican theory of the heavens
1597	Galileo writes to Kepler that he, too, is a supporter of the Copernican theory
1600	William Gilbert's *On the Magnet* founds the modern theory of magnetism
1604	Kepler publishes initial mathematical theory of optics
1609	Kepler's *New Astronomy* announces that the planets orbit the Sun in ellipses, not circles (Galileo disagrees)
	Galileo builds his first telescope and studies the heavens
1610	Galileo's *Starry Messenger* announces mountains and "seas" on the Earth's Moon and four moons orbiting Jupiter
1618	Outbreak of the Thirty Years' War
1619	Kepler's *Harmony of the Worlds* reveals mathematical law governing planetary distances and orbital velocities
1620	*Mayflower* arrives at Plymouth Rock
	Francis Bacon's *New Organon* describes experimental method for acquiring knowledge of nature and its "laws"
1628	William Harvey experimentally demonstrates the circulation of the blood
1632	Galileo's *Dialogue on the Two Great World Systems* leads to his trial and incarceration
1637	Rene Descartes' *Discourse on Method* claims only deductive reasoning leads to knowledge of nature
1638	Galileo's *Discourses on Two New Sciences* founds modern mechanics
1648	Treaty of Westphalia concludes the Thirty Years' War
1655	Christian Huyghens shows that curved motion is forced, not "natural"
1658	Robert Boyle and Robert Hooke build the first improved air pump
1660	The Royal Society for the Improvement of Knowledge founded in London
1664	Robert Hooke's *Micrografia* describes the world revealed by the compound microscope, paralleled by the work of Anton van Leeuwenhoek in Holland
1667	Paris Academy of Sciences founded
1684	Leibniz publishes first version of differential and integral calculus
1687	Isaac Newton's *Mathematical Principles of Natural Philosophy*
1688	England's Glorious Revolution changes the government bloodlessly
1690	John Locke's *Essay Concerning Human Understanding* proposes the Empirical theory of knowledge, contra Descartes' Rationalist theory
1704	Newton's *Optics* describes the experimental demonstration of properties of light and argues the corpuscular theory of light (appendix contains Newton's version of the calculus)

1709....................George Berkeley's *New Theory of Vision* begins his critique of modern science

1717....................Publication of the Leibniz-Clarke correspondence contrasts the Newtonian and Leibnizian conceptions of nature and knowledge of nature

1738....................Voltaire and his mistress, Madame du Châtelet, publish the first popular French account of Newtonian science, challenging the prevailing Cartesianism

1739....................David Hume's *Treatise of Human Nature* attacks the possibility of knowledge of nature, as opposed to probable beliefs about nature, and the overestimation of reason

1741....................Madame du Châtelet publishes an account of Leibniz's philosophy of nature

1747....................Madame du Châtelet begins the first, and still the only, French translation of Newton's *Mathematical Principles of Natural Philosophy*

1748....................Pierre Montesquieu's *Spirit of the Laws* proposes a naturalistic theory of society

1750....................Jean-Jacques Rousseau begins his attacks on science and technology as progressive, championing the passions over reason

1751....................First volume of the French *Encyclopédie* of science, technology, and crafts appears, edited by Denis Diderot (the 22nd and last volume appears in 1772)

1762....................Immanuel Kant's *Universal Natural History and Theory of the Heavens* proposes a mechanistic, Newtonian account of the origin of the Universe and Solar System

1776....................Declaration of Independence: American colonists rebel against the British Crown

............................Thomas Paine's *Common Sense* defends the American rebellion

............................James Watt and Matthew Boulton begin manufacture of Watt's improved steam engine

1781....................Kant's *Critique of Pure Reason* offers an idealist theory of knowledge of experience that escapes Hume's criticism of Rationalist and Empiricist theories of nature

............................British astronomer William Herschel discovers the planet Uranus

............................Lavoisier's "discovery" of oxygen and chemical "revolution"

............................Henry Cavendish dissociates water into "air" and oxygen

............................Treaty of Paris: British government accepts American independence

1789....................Outbreak of the French Revolution

1791....................Luigi Galvani discovers "animal" electricity

1794....................Claude Chappe's line-of-sight telegraph links Paris and Lille

1798....................Count Rumford's cannon-boring experiments challenge the caloric theory of heat

1799....................Pierre Simon Laplace's *Celestial Mechanics* proves the stability of the Solar System, "with no need for God"

............................Napoleon assumes dictatorial powers

1800....................Alessandro Volta describes first electrical battery, producing continuous current

1804....................Napoleon named emperor of France; Napoleonic Wars continue to 1815

1807....................Robert Fulton's steamboat travels up the Hudson River from New York to Albany

1808....................John Dalton's *New System of Chemical Philosophy* initiates the modern atomic theory of matter

1812....................Laplace's *Analytical Theory of Probabilities* identifies modern science with materialistic determinism

1815....................Napoleon defeated at Waterloo; monarchy restored

1820	Hans Christian Oersted shows the connection of electricity and magnetism
1823	Joseph Fourier’s *Analytical Theory of Heat* separates mathematical model and physics of heat
1830	George and Robert Stephenson’s Liverpool and Manchester (Steam) Railway opens
	First section of Auguste Comte’s *Course of Positive Philosophy*
	John Herschel’s *Preliminary Discourse on Natural Philosophy*
1831	Michael Faraday discovers the dynamo principle
	Charles Darwin begins his five-year voyage on H.M.S. *Beagle*
1838	Friedrich Wilhelm Bessell determines first distance to a star: 6 light years
1839	Charles Wheatstone and William Cooke, first commercial electric telegraph
1840	William Whewell’s *Philosophy of the Inductive Sciences, Based on Their Histories*
1843	John Stuart Mill, *A System of Logic*
1844	Samuel F. B. Morse’s electric telegraph links Washington, DC, and Baltimore
1846	Neptune discovered based solely on mathematical prediction
1851	Law of conservation of energy, William Thomson and Rudolf Clausius
1858	Alfred Russell Wallace’s letter to Darwin on evolution by natural selection and joint presentation of their independent researches
	Henry Bessemer opens first steel mill, Sheffield, England
1859	Charles Darwin’s *The Origin of Species*
1861	U.S. Civil War begins
1865	Unification of Germany under Kaiser Wilhelm and Bismarck
	U.S. Civil War ends
	James Clerk Maxwell’s unified electromagnetic theory of energy/light
	Gregor Mendel’s heredity experiments published in obscure journal
	Claude Bernard’s *Introduction to the Study of Experimental Medicine*
1866	Maxwell’s probability-based kinetic theory of gases proposed
	First successful transatlantic telegraph cable, based on physical theory
1868	Publication of Bernhard Riemann’s thesis introduces non-Euclidean geometry
1871	Franco-Prussian War: first war between France and Germany
	Charles Darwin’s *The Descent of Man*
1876	Alexander Graham Bell demonstrates the telephone at the Philadelphia Exhibition
	Nikolaus Otto introduces four-stroke internal combustion engine
1878	Charles Sanders Peirce publishes first article on Pragmatism
1879	Thomas Edison demonstrates incandescent electric light
1881	J. B. Stallo’s *The Concepts and Theories of Modern Physics*
1882	Edison opens first commercial central electricity-generating station
1883	Ernst Mach’s *The (Historical Development of the) Science of Mechanics*

1887....................Albert Michelson's invention of the interferometer; Michaelson and Edward Morley experiments challenging theory of the aether

1888....................Heinrich Hertz demonstrates electromagnetic waves predicted by Maxwell's theory

1896....................Henri Becquerel discovers radioactivity

............................Roentgen discovers X-rays

............................J. J. Thomson discovers the electron: atom has internal structure

1898....................Hertz's *The Science of Mechanics* (published posthumously)

1900....................Max Planck's initial quantization of electromagnetic energy hypothesis

............................Foundation of modern genetic theory

............................Sigmund Freud's *The Interpretation of Dreams*

1903....................Henri Poincaré, *Science and Hypothesis*

1904....................Pierre Duhem's *The Aim and Structure of Physical Theories*

1905....................Albert Einstein proposes a quantum theory of light, explaining the photoelectric effect

............................Einstein calculates the dimensions of molecules and argues for the reality of atoms and molecules

............................Einstein propounds the special theory of relativity

1910....................Ernest Rutherford proposes the Solar System model of the atom

............................First volume of Bertrand Russell and Alfred North Whitehead's *Principia Mathematica* is published, stimulating modern mathematical logic

1912....................Niels Bohr proposes the quantum theory of the atom

............................Henrietta Leavitt invents variable star method for calculating cosmic distances

1914....................Beginning of World War I

1915....................Einstein publishes his general theory of relativity

............................Alfred Wegener proposes the continental drift theory of Earth's surface

1918....................Harlow Shapley calculates dimensions of the Milky Way and Earth's position far from its center

............................End of World War I

............................Russell's "The Philosophy of Logical Atomism" founds analytical philosophy

1919....................The 100-inch telescope on Mount Wilson becomes operational

............................Ludwig Wittgenstein's *Tractatus Logico-Philosophicus* reinforces the analytical philosophy movement and leads to the rise of Logical Positivism

1923....................*Scopes* trial in Tennessee

1924....................Edwin P. Hubble, using 100-inch telescope, announces the existence of myriad galaxies beyond the Milky Way

1925....................Formulation of quantum mechanics by Werner Heisenberg and Erwin Schrödinger

1927....................Heisenberg uncertainty relations

............................Full "duality" of matter and energy established

............................Muller induces genetic mutations artificially

............................Percy Bridgman's *The Logic of Modern Physics*

1929....................Hubble announces expanding Universe

	Niels Bohr and Werner Heisenberg propose the Copenhagen interpretation of quantum mechanics
1930	The “new synthesis” of Darwinism and population genetics wins growing support
	Bohr proposes nonconservation of energy to “rescue” quantum mechanics
1932	Paul Dirac’s mathematics-based prediction of antimatter confirmed
	Discovery of the neutron by James Chadwick
	First particle accelerators become operational at Cambridge and Berkeley
1934	Karl Popper’s *The Logic of Scientific Discovery* (English publication, 1959)
1935	Ludwik Fleck’s *The Genesis and Development of a Scientific Idea*
1939	Discovery of fission
	Speculative Big Bang hypothesis for the origin of the Universe
	Beginning of World War II
1945	Atomic bombs dropped on Hiroshima and Nagasaki
	World War II ends
1946	George Gamow’s initial formulation of the Big Bang theory
1948	Steady-state theory of the Universe proposed by Fred Hoyle, Hermann Bondi, and Thomas Gold
	Gamow and collaborators predict microwave background radiation if the Big Bang theory is correct
	Carl Hempel and Paul Oppenheim propose hypothetical-deductive model of scientific reasoning
	Claude Shannon and Warren Weaver found modern information theory
1949	200-inch telescope becomes operational at Mount Palomar observatory
1950	Willard van Ormond Quine’s “Two Dogmas of Empiricism” attacks the basis of Logical Positivism and Empiricism
	National Science Foundation created
1953	James Watson and Francis Crick discover the structure of the DNA molecule
	Wittgenstein’s *Logical Investigations* published posthumously, reversing the conclusions of his 1919 *Tractatus*
1957	Soviet Union launches Sputniks 1 and 2 into orbit
1958	Norwood Russell Hanson, *Patterns of Discovery*
	Michael Polanyi’s *Personal Knowledge*
1962	Thomas Kuhn’s *The Structure of Scientific Revolutions*
	Quark theory of matter introduced by Murray Gell-Mann and George Zweig
	Rachel Carson’s *Silent Spring*
1965	Israel Scheffler’s *Science and Subjectivity*
	Microwave background radiation predicted by Gamow discovered by Arno Penzias and Robert Wilson
1966	Michel Foucault’s *The Order of Things*
1967	Jacques Derrida’s *On Grammatology*
1968	Plate tectonic/continental drift theory wins acceptance after 50 years

1975....................Paul Feyerabend’s *Against Method*

1979....................Steven Woolgar and Bruno Latour’s *Laboratory Life*

1980....................Vera Rubin’s theory of dark matter wins support from Alan Guth’s inflation theory of the Universe

............................Mary Hesse’s *Revolution and Reconstruction in the Sciences*

1981....................Arkansas court rules that creationism is not science

1984....................Andrew Pickering’s *Constructing Quarks*

1987....................Latour’s *Science in Action*

1989....................Experimental confirmation of CFC-caused ozone hole theory

1995....................Sixth and final quark discovered at FermiLab

1996....................Alan Sokal’s “social construction of quantum theory” hoax in social studies

1998....................Acceleration of expansion of the Universe discovered, attributed to dark energy

2000....................Human genome “decoded”

2001....................Philip Kitcher’s *Science, Truth and Democracy*

2002....................U.S. government rejects global warming treaty

2005....................Intelligent design controversy becomes a national issue

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Internet Resources:

1. Stanford University maintains the best Internet site for the history of Western philosophy, an online encyclopedia of philosophy with excellent entries on most of the people, ideas, and themes mentioned in this course. I suggest that you make it your primary reference resource: http://plato.stanford.edu.

2. An excellent resource in the history of Western science (and in European history generally) is maintained by Fordham University: www.fordham.edu/Halsall/science/sciencesbook.html.

3. There are many Internet sites devoted to great scientists and philosophers. Two of special interest and merit are devoted to Galileo and to Newton. The Galileo site is maintained by Rice University and puts Galileo in a rich contemporary context by providing lots of background information: http://galileo.rice.edu. The Newton Project not only provides background information on Newton's life and times, but has a constantly expanding list of Newton's works available online, especially many of his works on history and religion: www.newtonproject.ic.ac.uk.

4. Alan Sokal, of "Sokal Hoax" fame, maintains an excellent Web site of supportive as well as critical responses to his hoax, with many full texts and links to other sites with relevant texts. A fascinating collection of materials: http://www.physics.nyu.edu/faculty/sokal/.

5. To follow a theory that is "under construction," I suggest exploring the "birth pains" of String Theory as it struggles to win acceptance as the newest unified theory of matter, energy, and gravity: www.superstringtheory.com.