Chapter 2

Evolution, Creation, and the Philosophy of Science

Paul Thagard

Introduction

Debates about evolution and creation inevitably raise philosophical issues about the nature of scientific knowledge. What is a theory? What is an explanation? How is science different from non-science? How should theories be evaluated? Does science achieve truth? The aim of this chapter is to give a concise and accessible introduction to the philosophy of science, focusing on questions relevant to understanding evolution by natural selection, creation, and intelligent design. For the questions just listed, I state what I think is the best available answer and show how it applies to debates about evolution and creationism. I also indicate alternative answers that are preferred by other philosophers. I hope that the result will be useful for science educators and anyone else involved in controversies about evolution and creation.

What Are Theories and Explanations?

Theories Are Representations of Mechanisms

In ordinary speech, "theory" sometimes means an unsupported speculation, as in the phrase "just a theory." But many scientific theories are well established by a wealth of evidence; for example, relativity theory and quantum theory in physics, atomic theory in chemistry, genetic theory in biology, and the germ theory of disease in medicine. A theory is best understood as the representation of an explanatory mechanism, where a mechanism is a system of parts whose properties and interactions produce regular changes. A scientific explanation of something consists of showing how it results from the operations of a mechanism.

Consider a simple machine such as a manual can opener, whose parts usually include two handles hinged together at one end, a serrated wheel that cuts into the can, and a crank that operates gears that turn the wheel in order to remove the lid of the can. When you turn the crank, you exploit the properties of the parts such as their rigidity and their interactions such as the meshing of the gears to produce the desired change, cutting through the top of the can to remove the lid. Specifying this mechanism in terms of its parts, interactions, and resulting changes explains how cans have their lids removed. If the can opener is not working, its failure can usually be explained by defects in the mechanism, such as a broken crank.

I have described the can opener mechanism using words and sentences, but a fuller description would use visual representations such as pictures and diagrams. Perhaps while you were reading my verbal description you constructed a mental picture of using a can opener that made it easier for you to think about what the parts are and how they interact. An engineer might use mathematical representations that employ variables and equations to express concisely the forces and motions that enable the can opener to work. Thus representations of a mechanism on paper and in the mind can be verbal, pictorial, and/or mathematical.

Similarly, scientific theories represent mechanisms using a combination of ordinary words, pictures, and mathematics. For example, Newton mechanistically explained why bodies fall by describing their parts such as projectiles and planets, their interactions such as forces applied, and the resulting changes in speed and location. He used a combination of words, diagrams, and equations to show how motion results systematically from the interactions of objects. Table 2.1 concisely summarizes some of the important mechanisms employed in different areas of science, which vary in the kinds of representations they use. For example, physics uses more mathematical equations than cell biology, which uses more diagrams. The end result is the same, explaining how changes come about through systematic interactions of the parts of a system. What can count as a mechanism has changed in the history of science, from the simple parts and interactions of the Greeks, to Newton's ideas that allowed action at a distance, and to current views about complex dynamic systems such as those used in advanced robotics.

Table 2.1 Sketch of Some Important Mechanisms in Science

Science	*Parts*	*Interactions*	*Changes*
Physics	Objects such as projectiles and planets	Forces such as gravity	Motion
Chemistry	Elements, molecules	Mass, energy	Reactions
Geology—plate tectonics	Continents	Floating, collision	Continental drift, mountains, earthquakes
Neuroscience	Neurons, synapses	Electrochemical transmission	Brain activity, learning

Scientific theories often describe interacting mechanisms at different levels of organization. For example, the germ theory in medicine explains how people come down with influenza and other infectious diseases through the operation of microbes such as bacteria and viruses. Understanding these diseases requires attention to mechanisms that operate at several different levels, concerning social groups, organisms, cells, and molecules. Social groups are relevant to understanding such aspects of contagion as when you acquire a virus by shaking hands with someone you meet at a party. Relevant organisms are people's bodies and microbes that infect them, as when a virus infects your throat and makes it swollen. Viruses infect the cells in your throat through biochemical processes that enable them to bind with molecules on cell surfaces, invade the cells, and reproduce. Table 2.2 summarizes how medical theories explain disease by specifying mechanisms at interacting levels.

Levels are related in three ways, involving parts, interactions, and changes. The parts at one level are composed of parts at the next level down, and the interactions at the higher level are based on the interactions at the lower level, so that the changes at the higher level result from the changes at the lower level. For example, your sore throat results from infection by a virus (organism level) that occurs because the virus invades the cells in your throat (cell level) by means of chemical interactions with proteins on the cell surfaces (molecular level). A full understanding of disease requires specification of mechanisms at all relevant levels, including social groups, organisms, cells, and molecules.

Sources for the mechanistic account explanations and theories include: Bechtel (2006); Bechtel and Abrahamsen (2005); Bechtel and Richardson (1993); Craver (2007); Darden (2006); Machamer, Darden, and Craver (2000); Salmon (1984); Thagard (1999, 2006a, 2006b). Introductions to the philosophy of biology include Sterelny and Griffiths (1999) and Rosenberg and McShea (2007). Salmon (1989) reviews philosophical theories of scientific explanation.

Table 2.2 Levels of Mechanisms Relevant to Explaining Disease

Level	*Parts*	*Interactions*	*Changes*
Social groups	People	Contact	Contagion
Organisms	Bodies, microbes	Infection	Symptoms such as fever
Cells	Molecules such as proteins	Cell division, invasion	Cell growth, destruction
Molecules	Elements	Binding, reactions	Chemical reactions

Evolutionary Theory as Representation of Mechanisms

Similarly, evolutionary theory is best understood as the representation of mechanisms operating at several levels. Evolution by itself is not a mechanism, but rather a description of historical changes that Darwin described as "descent with modification." Humans and other species have developed from previous ones by modifying and preserving some of their characteristics. Darwin's great discovery was the mechanism of natural selection that explains how species can evolve by the competition to survive and reproduce by adapting to environments. In this mechanism, the parts are the different organisms in their environments, the interactions include feeding and reproduction, and the changes are the occurrences of members of species with different characteristics.

The great gap in Darwin's original theory of evolution by natural selection is that he lacked a good account of how variations occur in organisms and are passed on to their offspring. This gap was filled early in the 20th century by genetic theory which explained how characteristics can be inherited through the transmission of genes, and how variation can occur through genetic mutation. In the second half of that century, the molecular mechanisms for genetic transmission and variation became understood as the result of biochemical interactions such as those involving DNA and RNA. Thus evolutionary theory can be understand as representation of mechanisms operating at several different but interacting levels: natural selection, genetics, and molecular biology, as summarized in Table 2.3. Social mechanisms are indirectly relevant to evolutionary theory, through interactions of groups of organisms and interspecies competition. For the mechanisms of evolutionary theory, see textbooks such as Ridley (2003).

These mechanisms are interconnected through parts, interactions, and changes. Organisms consist of cells that include genes, which are sequences of DNA. The interactions of organisms derive partly from their genetic

Table 2.3 Mechanisms in Evolutionary Theory

Mechanism	*Parts*	*Interactions*	*Changes*
Natural selection	Organisms	Competition to survive and reproduce	Occurrence of characteristics; new species; extinction
Genetics	Genes, alleles	Mutation, protein production	Prevalence of genes
Biochemistry	Molecules such as DNA	Combination, chemical reactions	Structure of DNA

programming, based on the operations of DNA, RNA, and other molecules. Hence changes at the level of species and organisms can be understood partly in terms of changes in genes and molecules, allowing also for changes in physical environments (e.g., climate) and in social environments (e.g., culture).

Representation of mechanisms in evolutionary biology primarily uses words and sentences, but pictures and mathematics are also sometimes useful. Since Darwin, depictions of descent with modification have often used tree diagrams, such as Figure 2.1; see Novick and Catley (2007) for a discussion of hierarchical diagrams that depict evolutionary histories among species. It is hard to picture processes of natural selection and genetics, but graphs can be used to show the changing frequencies of characteristics and genes in a population of organisms. Cell and molecular biology frequently use diagrams to depict structures such as the parts of cells and amino acids that constitute DNA, as well as processes such as cell division and DNA recombination. Mathematical equations are also sometimes part of the representation of evolutionary mechanisms, especially in population genetics. For example, the Hardy–Weinberg law is an equation that specifies the relationship between the frequency of alleles and the genotype of the population. Hence evolutionary theory combines verbal, pictorial, and mathematical representations of mechanisms that include natural selection, genetics, and molecular interactions. Together, these mechanisms explain a wide array of biological changes such as the development of new species.

In contrast, the hypotheses of divine creation and intelligent design are clearly not mechanistic theories. Theorists such as Dembski (1999) postulate

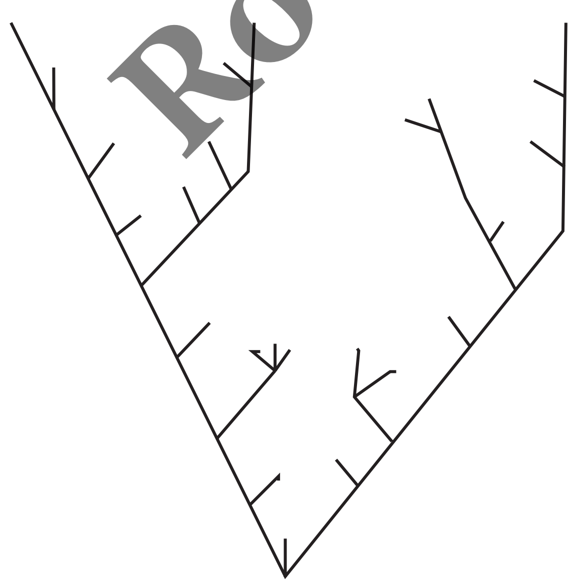

Figure 2.1 Visual representation of branching evolution of species: Darwin's tree of life, simplified.

that God created the universe, including the species on our planet, without giving any indication of how. Indeed, no such indication is possible, as God is a supernatural being, independent of time and space, whose effects on the world must occur in violation of basic laws of physics such as conservation of energy. By definition God cannot be part of a physical mechanism, so creationism cannot provide the kind of mechanistic explanation that has been the hallmark of science for centuries. Even if physical mechanisms were created by God, it remains totally mysterious how miraculous interventions could occur.

Alternative Views of Theories and Explanations

The mechanistic view of explanations and theories has become increasingly prominent in the philosophy of science in recent years, as the references in the next subsection document. But it is by no means the only view, and to avoid dogmatism I will briefly point to alternatives. The classical view of theories developed by the logical empiricists is that a theory is a set of universal sentences ideally expressed in a formal language such as predicate calculus. From this perspective, evolutionary theory should be stated as a set of axioms, but no one has produced more than sketchy formalizations of natural selection and population genetics. On the classical view, an explanation is a deductive argument that looks like a proof in a formal system, showing how descriptions of phenomena to be explained follow logically from the axioms that constitute a theory. Sources of the logical empiricist account of theories and explanations include Hempel (1965, 1966) and Nagel (1961). Deductive explanations can sometimes be found in highly mathematical areas of science such as physics, but are rare in evolutionary biology. The classical view of explanation can be loosened by allowing that what is explained need only be made probable by a theory, but relevant probabilities are hard to find in applications of evolutionary theory. In contrast, the account of evolutionary theory and explanation in terms of representation and application of mechanisms fits well with scientific practice. On the "erotetic" view of explanation, an explanation is just an answer to a why question, but this view fails to differentiate good scientific explanations from fanciful answers.

An alternative to the classical view of theories is the semantic (set-theoretic) conception that rejected the idea of a theory as a specific linguistic formulation. On this conception, a theory is a structure that serves to pick a class of models out of a general class of models. Here a model is not anything concrete, but rather a mathematical abstraction consisting of a set of objects and relations among them. It can be used to make empirical claims that the models that constitute the intended applications of the theory are among the models picked out by the theory. To specify a theory, we need to define a predicate such as "x is a biological population" by stating in informal set theory a series of axioms characterizing those objects that fall under the predicate. A theoretical claim then says that biological populations in the real world are included in the abstract models defined by the set-theoretic predicate. Suppe (1977) includes discussions of the set-theoretic alternative, which was applied to biology by Thompson (1989). Unfortunately, such set-theoretic axiomatizations are as difficult to produce as the syntactic ones sought by the classical view of theories. In contrast, the much more informal view of theories as involving several kinds of representation does not require reconstruction of scientific practice.

How Is Science Different from Pseudoscience?

Science Has Typical Features

Debates about whether creationism and intelligent design theory are scientific would benefit from a strict definition of science that distinguish it sharply from non-science or pseudoscience. (By pseudoscience I mean a non-scientific enterprise that purports to be scientific.) Some philosophers have proposed criteria such as verifiability or falsifiability as distinguishing marks of science, but other philosophers have pointed out serious problems with these criteria. As I will discuss further below, precise versions of these criteria tend to rule out as scientific even sciences such as physics, whereas loose versions of them tend to include just about anything. It therefore looks hopeless to come up with a definition of science that would enable us to say that a field or theory is scientific if and only if it has properties A, B, and C. Some philosophers have concluded that the problem of demarcating science from pseudoscience is unsolvable (Laudan, 1983).

We should not, however, be surprised or dismayed by failure to define science exactly, because few concepts outside mathematics have precise definitions. To take a mundane example, my dictionary defines *restaurant* as a "public eating place," but this seems too loose: my department has a lounge where people bring their lunches, but it is not a restaurant, nor is a university residence cafeteria. Much research in cognitive science suggests that concepts are characterized, not by strict definitions, but by descriptions of prototypical features and standard examples.

For science, our most standard examples are physics, chemistry, and biology, so we can ask what features are most typical of them and their subfields. Identifying such features would not provide the necessary and sufficient conditions that are needed for a sharp definition, but could nevertheless provide a profile of science that could serve to discriminate it from pseudoscience. We can also develop a profile of pseudoscience by looking at the typical features of fields that have falsely purported to be scientific, such as alchemy and astrology. Table 2.4 provides such profiles of science and pseudoscience. Earlier attempts to demarcate science from pseudoscience by means of prototypical profiles include Thagard (1988) and Derksen (1993).

Table 2.4 Profiles of Science and Pseudoscience

Science	*Pseudoscience*
Explains using mechanisms.	Lacks mechanistic explanations.
Uses correlation thinking, which applies statistical methods to find patterns in nature.	Uses dogmatic assertions, or resemblance thinking, which infers that things are causally related merely because they are similar.
Practitioners care about evaluating theories in relation to alternative ones.	Practitioners are oblivious to alternative theories.
Uses simple theories that have broad explanatory power.	Uses nonsimple theories that require many extra hypotheses for particular explanations.
Progresses over time by developing new theories that explain newly discovered facts.	Stagnant in doctrine and applications.

It should be obvious that physics, chemistry, and biology over the past several hundred years have matched very well the profile for science. In contrast, astrology and graphology (analyzing people's personality from their handwriting) match much better the profile for pseudoscience. Astrology lacks mechanistic explanations, in that it has never been able to say how the alignment of the stars and planets could affect people's lives. Its generalizations such as that being born under the influence of the planet Mars will make a person warlike are based either on dogmatic assertions or on resemblance theories (the red planet resembles blood which is spilled in war). Astrologers ignore alternative explanations of people's personalities such as the genetic and social learning ones provided by modern psychology. Astrologers can always explain an event by coming up with an account of how a mixture of celestial influences affect one's fate. Finally, astrology has certainly been stagnant, failing to develop new theories and empirical applications over many hundreds of years. The contrast is dramatic with scientific fields such as physics, chemistry, and biology, all of which have had fabulous developments in new theories, instruments, empirical evidence, and technological applications over the same time period.

In sum, the problem of demarcating science from pseudoscience is manageable despite the lack of a strict definition of science. By attending to the differences in intellectual practice and historical development, we can develop profiles of science and pseudoscience that specify their prototypical features. We can then categorize a field or theory as scientific or pseudoscientific by matching it against the two profiles.

The Scientific Status of Evolution and Creation

Evolutionary theory, encompassing natural selection, genetics, and molecular biology, clearly fits the profile of science provided in Table 2.4. I have already described how it uses mechanistic explanations, and it makes generalizations about the properties of populations of organisms using statistical techniques rather than dogmatic assertion or thinking based on mere similarities. Beginning with Darwin's systematic comparison in *The Origin of Species* of his theory of evolution by natural selection with the dominant theory of his day, divine creation, evolutionary biologists have engaged in debates about alternative theories. Natural selection and genetics have great explanatory power described in the next section. Finally, evolutionary theory has clearly progressed in the century and a half since Darwin published the *Origin*, through the development of whole new fields such as genetics and molecular biology. According to the profile of science in Table 2.4, evolution is as scientific as any field you can name.

In contrast, creationism and its current version, intelligent design, fit well the profile of pseudoscience. We have already seen that they lack mechanistic explanations, and many of their claims are based on dogmatic assertions rather than on statistical analysis. The proponents of divine creation remain blind to the substantial explanatory successes of evolutionary theory, and address it only to be able to reject it in line with their religious motivations. As I discuss further in connection with theory evaluation below, creation theory can potentially explain anything, merely by adding the additional hypothesis that God wanted it to happen. The price, however, is great loss in simplicity, as such explanations require a separate hypothesis about God's plan for each fact explained. Finally, the theory that species originated through divine creation has not been progressive, having advanced little since the early 19th century. Given its dependence on religious doctrine rather than hypothesis generation based on empirical observation, such stagnation was inevitable. We should therefore have no hesitation in concluding that creationism and intelligent design theory are not scientific. On intelligent design, see also Sober (2007).

Alternative Views of Demarcation

Science textbooks often begin by saying that science proceeds by forming hypotheses, using them to make predictions, and then performing experiments to see whether the predictions are true. If the experiments fit the predictions, then the hypotheses are said to be confirmed (verified), but if the predictions fail then the hypotheses are disconfirmed (falsified). According to the philosophical movement called logical positivism, what makes science meaningful is verifiability: theories can be used to make predictions that can be verified (Ayer, 1946).

The principle that science is marked by verifiability has two major problems. First, no one ever managed to state the principle of verifiability in a precise and plausible way that excludes metaphysics (the main target of the logical positivists) without excluding science as well. Second, the principle itself seems to be unverifiable and hence meaningless metaphysics (according to the positivists) rather than scientific. Undoubtedly, science is concerned with forming hypotheses, making predictions, and performing experiments, but this practice cannot be codified into a strict definition that by itself demarcates science from non-science. Instead, I have included concern with evaluating the explanatory power of theories as one of the features of my profile of prototypical science, but verifiability should not be intended to perform the demarcation function all by itself.

Falsifiability is also often stated as *the* mark of a scientific theory, but has similar problems to verifiability. Karl Popper (1959) thought that confirmation of theories is too easy to come by, so what makes a field scientific is that its practitioners try to do experiments that could disconfirm their theories and thereby show them to be false. But even scientific theories are not capable of strict falsification, for the deduction of an observation statement from a theory always requires the use of auxiliary hypotheses, and it is always logically possible to reject one of these rather than the theory. For example, if your theory makes a prediction that is disconfirmed by experiment, you can always suppose that the experiment failed because of technical problems such as poor design or malfunctioning instruments, rather than because the theory was false. In the history of science, rejection of theories on the basis of failed predictions is extremely rare. When theories are rejected and taken to be falsified, it is because they have been replaced by theories with greater explanatory power. Hence rather than thinking of verification and falsification as two-place relations between hypotheses and observations, we should think of theory evaluation as a more complex competition between alternative theories that purport to explain the facts. Hence verification and falsification are only facets of scientific practice as indicated in the aspects of my profile citing concern with theory evaluation, not knock-down features of what makes a field scientific. Thus verifiability and falsifiability are poor criteria for demarcating science from pseudoscience, and hence useless by themselves in trying to distinguish evolutionary theory from creationism. Problems with using falsifiability as the mark of science were identified by Duhem (1954), Quine (1963), and Lakatos (1970).

How Are Scientific Theories Evaluated?

Theory Choice Is Inference to the Best Explanation

As I remarked in discussing the demarcation problem, the acceptance of a scientific theory is rarely based just on how well it makes predictions. Usually, there is more than one candidate theory for explaining the relevant data, and scientists need to pick the best one. Once a science is underway with an established theory, proponents of a new theory must show that it is superior. For example, Copernicus had to argue that his heliocentric theory provided a better fit with the observed motions of the planets than did Ptolemy's theory. Similarly, Lavoisier had to show that his oxygen theory of combustion provided a better explanation than the accepted phlogiston theory. Theory choice requires evaluating the available competing theories to determine which of them provides the best explanation of all the relevant data.

The two main criteria for evaluating theories are explanatory breadth and simplicity. One theory has more explanatory breadth than its competitor if it explains more classes of facts. For example, the theory that dinosaurs became extinct as the result of an asteroid hitting the Earth explains why there is an unusual layer of earth that was deposited around the time that dinosaur extinction occurred, a fact that other theories such as climate change cannot easily accommodate. Explanatory breadth needs to be balanced against another criterion, simplicity, which concerns how many special assumptions a theory has to make in order to accomplish its explanations. Lavoisier's oxygen theory had more explanatory breadth than the established phlogiston theory because it could explain why burning bodies gain rather than lose weight. But defenders of the phlogiston theory tried to save it by hypothesizing that the phlogiston supposedly given off during combustion had negative weight. This hypothesis helped the explanatory breadth of phlogiston theory at the cost of simplicity, introducing a special assumption. Similarly, the impressive explanatory breadth of the Ptolemaic theory came at the expense of simplicity, because it had to make assumptions about numerous epicycles for the planets in order to account for the observed motion.

Inference to the best explanation is not only used in science, but also in law, medicine, and everyday life. Your doctor's diagnosis is an inference about what disease provides the best explanation of your symptoms and test results. A detective's judgment that a suspect is responsible for a murder is based on the inference that this hypothesis is the best explanation of the available evidence. In addition to explanatory breadth and simplicity, the detective's confidence is often increased by being able to provide a motive such as anger or jealousy that explains why the suspect murdered the victim. Similarly, a scientific hypothesis gains support if in addition to explaining a variety of facts we can explain why the hypothesis is true. Such deeper explanations require identifying an underlying mechanism, as when Newton explained why planets revolve around the sun as the result of gravity, and atomic theory explained how oxygen combines with other elements to produce combustion. Hence the best scientific hypotheses should provide explanations that are broad (explaining a lot), deep (being themselves explained), and simple (requiring few additional assumptions). An additional factor relevant to picking the best explanation is how well a set of hypotheses fit with other accepted theories and facts. In sum, we accept a theory as the best explanation if it is more coherent with all available information than its alternatives. The view that theory evaluation in science is inference to the best explanation is defended by Thagard (1988) and Lipton (2004).

Evaluating Evolution and Creation

When creationists maintain that intelligent design theory should be taught in biology classes along with (or instead of) evolutionary theory, they assume that creationism is a reasonable alternative. There have been times in the history of science when the available evidence made it difficult to determine which of competing theories was best. For example, in the 18th century, it was not clear whether the wave theory of light or the particle theory was superior, since each could explain some observed phenomena that the other had trouble with. Teaching creationism along with evolutionary theory would be reasonable if it came even close to providing the best explanation of the relevant facts.

In the early 19th century, leading scientists as well as theologians extolled how divine creation beautifully explained biological facts. No alternative explanation of the complexity of life was available then, so it was reasonable to infer that creation was responsible for facts such as the diversity of species. In 1859, however, Darwin's *Origin* changed the situation radically, when he showed that evolution by natural selection provides a unified explanation of a broad range of facts involving the fossil record, the complexity of organs, extinction, and the geographical distribution of species. Since then, the explanatory superiority of evolution over creation has become increasingly evident, as evolutionary theory has progressed to explain more and more facts, for example the development of bacteria that are resistant to antibiotics. Moreover, evolutionary theory has been progressively deepened, as genetic theory came to provide a mechanism for inheritance and variability, and as molecular biology provided mechanisms for genetics.

In principle, divine creation could explain everything in biology including the appearance of evolution, by postulating that God wanted to set things up so it looked like species have evolved. But then creation theory fails on the criterion of simplicity, because it needs a special assumption about God's intentions and actions for each fact explained. Why, for example, did he set the world up in such a way that bacteria could become resistant to antibiotics? Because of the simplicity problem, and the lack of mechanistic explanations, it is fair to evaluate the explanatory power of creationism as very poor. Proponents of intelligent design maintain that only their approach can explain "irreducible complexity" found in nature, but natural selection and genetics have gone a long way to explaining organs as complex as the eye. Many people have the intuition that evolution by natural selection is not powerful enough to have produced the marvelous capacities of the human mind, but great advances have been made in understanding how mental processes are in fact brain processes. Moreover, much is known about how human brains evolved. Hence creationism and intelligent design have no explanatory advantages over evolutionary theory, and they have many disadvantages such as lack of mechanisms and inability to account without special assumptions for facts like the fossil record. Evolution is so superior to creation as the best explanation of a huge array of biological facts that it is not reasonable for science education to include intelligent design as an alternative view. A detailed theory of explanatory coherence with many scientific applications, including Darwin versus creation, is found in Thagard (1992). I provide a comparison of the explanatory coherence of materialist philosophy and science versus creationism and mind–body dualism in Thagard (2000).

If creationism is so inferior to evolution in explanatory coherence, why do so many people still espouse it? The answer is complex, involving both social factors such as the transmission of religious beliefs from parents to children, and psychological factors such as the emotional appeal of religious views about God, the afterlife, and morality. Many people believe that life would be pointless and amoral without the presence of God and the prospect of immortality. The story of divine creation fits well with appealing views about the non-material nature of the mind that make it capable of free will and existence beyond death. Creationism lacks scientific explanatory coherence, but it has enormous emotional coherence with many people's goals and everyday social experience (Thagard, 2006a). For many students, evolutionary theory has negative personal and social implications (Brem, Ranney, & Schindel, 2003). Hence pointing out the explanatory advantages of evolution over creationism rarely has any effect on the belief systems of true believers. A full alternative to the creationist world view requires not only evolutionary theory but also a materialist theory of mind and new philosophical theories about morality and the meaning of life (Thagard, 2010).

Alternative Views of Theory Evaluation

Many philosophers do not endorse the view I have presented that theory evaluation is inference to the best explanation. There are still proponents of the hypothetico-deductive view of confirmation, according to which a theory rises or falls based on the success or failures of its predictions (Hempel, 1965). I would argue that this view neglects both the comparative nature of theory acceptance and the prevalence of explanation rather than deductive prediction as the relation between theories and facts.

The most sophisticated alternative to inference to the best explanation is Bayesianism, which contends that theory evaluation is a matter of picking the most probable theory (Earman, 1992; Howson & Urbach, 1989). Probability is calculated via Bayes' theorem, which derives the probability of a hypothesis given the evidence from the result of multiplying its prior probability by the probability of the evidence given the hypothesis, all divided by the probability of the evidence. Use of Bayes' theorem is fine when we have objective information about probabilities, for example when we know the frequency with which someone has a symptom if they have a disease. But Bayes' theorem is very hard to apply objectively in cases such as evolution versus creation, because little is known about, for example, the probability of the fossil record given evolution versus its probability given creation.

Postmodernists would claim that the whole idea of rational theory evaluation is a myth: the theory with the most powerful proponents wins. Science is just a social construction. But the history of science is full of cases where objective theory evaluation has occurred because scientists have systematically compared competing theories with respect to how well they explain the evidence. For arguments against social constructivism, see Thagard (1999).

Is Science True?

Science Can Achieve Approximate Truth

It has become fashionable to try to reconcile science and religion by saying that they operate in different domains, or that they constitute separate but equal ways of knowing. Although creationist proponents of intelligent design make a show of giving empirical arguments for their views, the basis of these views is clearly religious faith rather than scientific observation and theorizing. Is there any reason to think that science is better than faith in arriving at the truth about the world? Critics of science sometimes discount it as just another kind of faith.

There are good reasons to be skeptical of claims that faith can be a reliable source of knowledge about the world. The first is that faith provides no way of choosing between different views. If you are going to base your religious beliefs on faith, which religion should you choose? Faith can be used to defend belief in Judaism, Islam, Hinduism, Buddhism, as well as many variants of Christianity, from Catholicism to Mormonism. Obviously they cannot all be right, and faith provides no way of evaluating them with respect to each other or more ancient forms of polytheism. Sociologically, it is evident that most people adopt a faith based on the family and community they grow up in, so faith appears to be an accident of birth and association rather than a source of knowledge.

The second reason to be skeptical about faith-based claims is that religion has a poor track record of arriving at reliable knowledge about the world. Classic examples include the rejection by the Catholic Church of the heliocentric theories of Copernicus and Galileo, and bible-based claims that the universe is only about 6,000 years old rather than the billions of years suggested by physical evidence. Religious faith has made only negative contributions to the vast amount of scientific knowledge that has accumulated over the past 400 years.

But is science actually any more successful at arriving at the truth? Some philosophers of science have advocated the "pessimistic induction" that all scientific theories eventually turn out to be false. Good examples of scientific theories that were widely accepted but later rejected include the humoral theory of disease, the caloric theory of heat, and ether theories of electromagnetism. Perhaps we should expect that current scientific theories will eventually bite the dust too. Even the two pillars of modern physics, relativity and quantum theory, are problematic in that they seem to be incompatible with each other; and scientists are attempting to use approaches such as string theory and quantum gravity to develop a new synthesis. If scientific theories are ephemeral, why should we take science as telling us how the world really is? Perhaps accepting a scientific theory, even one with a lot of evidence behind, involves a leap of faith not much different from religion.

The pessimistic induction about scientific theories, however, gives a distorted picture of the history of science. Most of the examples that support it are centuries old, whereas the 20th century witnessed a remarkable accumulation of knowledge in physics, chemistry, and biology. Relativity theory and quantum theory introduced conceptions not found in Newtonian mechanics, but Newton's theory of motion survives as a good approximation to the behavior of bodies that are not in intense gravitational fields or very small. Although explaining a lot is no guarantee of truth, as examples such as the wave theory of light show, theories that have not only broadened by explanation new classes of facts but also deepened by the discovery of underlying mechanisms have stood the test of time. Hence we can justify the cautiously optimistic induction that theories which have both broadened and deepened are at least approximately true (Thagard, 2007).

One of the major reasons for believing that scientific theories have some grip on truth is the huge success of technological applications. Enormously successful technologies such as computers, televisions, and DVD players are based on physical theories about electrons and electromagnetic waves. Effective drugs such as antibiotics and cholesterol-lowering medications are based on biological accounts such as bacterial theories of diseases and biochemical theories of metabolism. The best explanation of the technological applicability of such technologies is that the underlying theories are at least approximately true. Hence because of technological success and the past century's accumulation of scientific results, we have good reason to believe that scientific theories are often at least approximately true. Faith-based approaches have no such track record. For further defense of scientific realism, see Psillos (1999) and Thagard (1988, 1999, 2010).

The Truth of Evolution and Creation

Do we have any reason to believe that evolutionary theory is true? Beginning with Darwin, evidence has accumulated both that species have evolved and that natural selection is the major mechanism responsible for evolution. Genetics provided mechanisms for variability and inheritance, and molecular biology provided mechanisms for genetics. Thus evolutionary theory has broadened and deepened in the century and a half since Darwin began it, so my cautiously optimistic induction about the development of scientific knowledge applies to it: we have good reason to believe that evolutionary theory is at least approximately true. The truth of the theory of evolution is not so strongly supported by technological applications as modern physics, but there are at least a few developments such as genetic engineering that only make sense in the light of evolution.

In contrast, only faith supports the doctrine of divine creation, and we have already seen that faith is a highly unreliable guide to truth. There is no epistemological reason to suppose that science education needs to be based on faith as well as on the kinds of evidence collection, experimentation, and constrained theorizing that have served modern science so well. Softer views on the compatibility of religion and evolutionary theory include Gould (1999). Dawkins (2006) argues that science requires the rejection of religion.

Alternative Views of Scientific Truth

I have been defending the position called scientific realism, which says that science aims and often succeeds in developing theories that truly represent the world. Some philosophers reject realism in favor of instrumentalism, according to which we are only justified in saying that theories are useful tools for prediction, not that they are true. Van Fraassen (1980) defends a trenchant version of anti-realism that he calls constructive empiricism, and a later book argues for compatibility of this view of science with religious faith (van Fraassen, 2002). Some sociologists and historians reject realism in favor of social constructivism, which claims that there is no such thing as truth as the development of science can be explained purely by social forces. Proponents of social constructivism include Barnes (1985) and Latour and Woolgar (1986).

Conclusion

I have tried to provide a concise guide to current ideas in the philosophy of science that are highly relevant to debates about evolution and creation. Scientific theories are representations of explanatory mechanisms, so it is clear that creationism and intelligent design do not provide scientific explanations. There is no one feature that defines science, but, in addition to explanatory mechanisms, creationism lacks additional features that are characteristic of science, such as critical evaluation of competing theories. Scientific theories are evaluated by comparing the breadth and depth of their explanations, and theories of creation and intelligent design are severely lacking on both these dimensions. Finally, we have good reason to believe that evolutionary theory is at least approximately truth, because of the breadth and depth of its explanations. In sum, there is no reason to treat creation and intelligent design as serious competitors for the modern version of the theory of evolution by natural selection.

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