The Nature of Science:

Methods for Seeking Natural Patterns in the Universe
Using Rationalism and Empiricism

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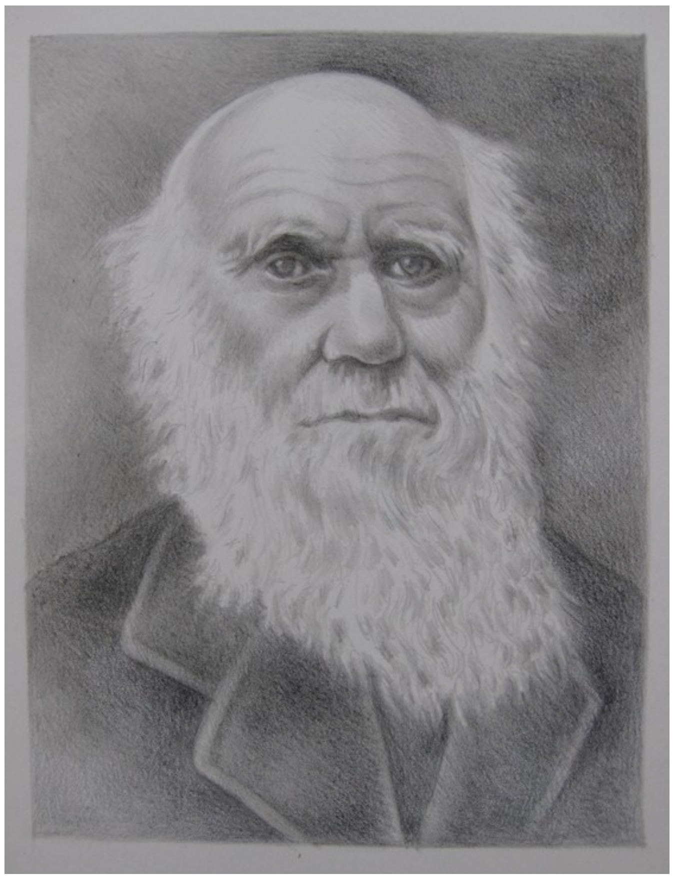

Darwin
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Introduction

Fascination with science often starts at an early age, as it did with me. Many students are initially attracted, as I was, to the vast body of knowledge our culture associates with science. Much of this knowledge is conveyed through television, the Internet, magazines, books, and teachers. Through these venues, scientific ideas are often mixed with speculation and beliefs that are, strictly speaking, extraneous to the deliverances of science. In science classrooms students continue to learn science through books, computers, and teachers. Occasionally, students get a glimpse of scientific methodologies through experimental design and peer review, but this is the exception. Rather than being taught the ways that science arrives at its conclusions, students are often taught the conclusions at which science arrives.

A deep and meaningful understanding of science does not come from learning its content alone, rather, one needs an awareness of how scientific knowledge is gathered and accepted. Many philosophers and scientists have written and continue to write about the nature of science. We will explore the nature of science by examining the characteristics of science as defined by the 1982 Rev. Bill McLean et al. v. Arkansas BOE (act 509), which tested a bid to give intelligent design equal standing with modern evolutionary theory. This legal definition is well suited for our purpose as it reflects the views of philosophers of science, scientists, science educators, and many theologians.

Judge Overton, writing for the 1982 case, listed five characteristics of science:

1. It is guided by natural law.
2. Explanations are in reference to natural law.
3. Hypotheses are testable against the empirical world.
4. Conclusions are tentative.
5. Theories and hypotheses are falsifiable (p. 380).

Guided by Natural Law

In both its investigations and explanations science assumes that the universe operates according to natural law. The implications and consequences of this self-imposed boundary are important to understand. If the universe is guided by natural law then it works in a predictable, empirically testable and knowable manner. Natural laws that govern interactions between matter and energy can be recognized and modeled. Models can then be used to make predictions given a set of initial conditions. The natural law boundary also requires that cause and effect relationships be viewed in the light of natural law. Thus, cause and effect relations cannot violate natural law. This boundary also limits what science can say about the existence of that which is beyond natural law, the supernatural. According to Robert Pennock science, ". . . is neither theistic nor atheistic in the ontological sense, but is agnostic, leaving God as a possibility that is outside the boundary of its methods of investigation" (p. 337).

Explanations are in Reference to Natural Law

If we assume the world operates according to natural law then it follows that our methodologies, descriptions, and explanations must be in reference to natural law. In science, causes and effects are viewed purely in the context of natural law. Scientific explanations, as such, cannot invoke the supernatural; all causes must be considered natural. Adopting a methodology that assumes natural causes has allowed science to reach across cultural divides. Kenrick and Davis observe, "Modern science has dropped the mythological and theological in favor of explanations couched in terms of natural causes. This approach is called methodological naturalism, and its results have achieved an unprecedented degree of corroboration and acceptance across cultural divides" (p. 205).

Testable Against the Empirical World

Scientific hypotheses, theories, and laws are testable against the empirical world. The concept of preferring ideas that are testable against the empirical world constitutes the very engine of science. Let us start with some definitions.

A scientific hypothesis is a prediction that can be tested. A hypothetical idea that cannot presently be tested is referred to as speculation. It is possible for a scientific hypothesis to be tested with no apparent counter-instances in which case it may achieve lawful status. A scientific law is a statement and or mathematical expression that describes a regularity in nature. Although the law may have defined boundaries it enjoys repeated, successful, independent empirical verifications. A scientific theory is a combination of well-tested hypotheses designed to explain a natural phenomenon. Scientific theories utilize multiple lines of evidence. Scientific theories may include scientific laws within their framework and can sometimes be used to derive known scientific laws. Scientific theories do not become scientific laws. Scientific laws and theories share important characteristics:

- They are models that approximate reality.
- They are repeatedly verified empirically independently of the theories or laws themselves.
- They are internally coherent.
- They are externally consistent with other scientific findings.
- They provide useful and dependable predictions.
- They are productive in that they lead to fruitful avenues of investigation and discovery.
- They are tentative in that limits or boundaries may be fine tuned as instruments or measurements allow us to explore the world with greater resolution.

Michael Ruse (1999) points out that William Whewell believed the best kind of science seeks a consilience of inductions in which inductions from different areas of science are explained by the same set of principles (p. 58). The idea of consilience also applies to converging lines of evidence, as when investigations in different areas of science dovetail to produce mutually reinforcing results. In the words of Whewell, "The Consilience of Inductions *takes place when an Induction, obtained from one class of facts, coincides with an Induction, obtained from another different class*. *This Consilience is a test of the truth of the Theory in which it occurs*" (p. 139). Major discoveries in physics, biology, geology, chemistry, and paleontology have served as converging lines of evidence in support of Darwin's theory of evolution by natural selection. Mendel's laws of inheritance, radiometric dating, plate tectonic theory, and new fossil discoveries, just to name a few, have served as a consilience of inductions in support of Darwin's theory.

The concept of testability is critical in our understanding of how hypotheses become accepted as scientific knowledge. Placing the highest value on ideas that are testable against the empirical world has consequences for knowledge gained through authority and for supernatural explanations.

Authority is the most common way to access knowledge. Leaders, experts, friends, books, visual and written media provide us with knowledge. There is a great comfort and familiarity with this epistemic method. The belief of an authority often determines the knowledge we value. This is where adding knowledge to science is very different. It is not enough for an authority to make a claim even if it is rational. An authoritative claim must be open to testing. Culture, language, or religion provides no special status for those who take on the role of independent checker. A person's or a group's beliefs have no purchasing power in science; only rational argument combined with evidence can finally justify a scientific theory. The scientific community is worldwide. Working scientists represent diverse cultural and religious backgrounds; however, as scientists they are constrained by empirical evidence. If gathering knowledge were a card game, empiricism would trump all others.

The supernatural is by definition above or beyond natural law. Supernatural hypotheses cannot be independently and reliably verified using empirical methods. On the other hand, the methodological naturalism used by science has often produced repeatable naturalistic explanations for phenomena that were once viewed as having supernatural causes such as weather and human illness. These naturalistic explanations have enjoyed great predictive success. Requiring that ideas in science be testable against the empirical world, testable by no one in particular, has made the knowledge gained by science public. Claims of secret knowledge or powers must be open to independent empirical testing. If these claims are not open to such investigations, they have no hope for being included in the body of knowledge we call science.

The process of putting forth positive evidence that can be tested by the scientific community plays out in scientific journals. This empirically driven, peer review process cultivates creativity, curiosity, skepticism, and ensures that no one can have the final say. The ideas of which science is most sure are ones that have withstood numerous independent empirical verifications. There is an important distinction between what scientists can claim in a scientific journal and what they can profess within popular venues such as the media or books. Like any citizen, a scientist can put forth logical or illogical speculation (ideas that cannot be presently tested) within these popular venues. It is important for scientists to be creative and speculate freely. In the end, however, it is an empirically based decentralized checking process that determines whether or not these ideas make useful and dependable predictions, a process that occurs in the world of scientific journals. Jerry Coyne rightly observes, "The gold standard for modern scientific achievement is the publication of new results in a peer-reviewed scientific journal" (p. 32).

Conclusions are Tentative

If no one can have the final say then putative truths handed down by authority cannot flourish. Stephen J. Gould (1941-2002) maintained that the very essence of science is to be a method devised to undermine proof by authority (Gould, p. 31). Scientific ideas must always be open to review in the light of new evidence. According to Jonathan Rauch, ". . . we must all take seriously the idea that any and all of us might, at any time, be wrong. Taking seriously the idea that we might be wrong is not exactly a dogma. It is, rather, an intellectual style, an attitude or ethic" (p. 45). The tentative nature of science embraces pragmatism because it emphasizes the mutating, growing nature of the human intellectual enterprise. The American psychologist/philosopher William James (1842-1910) asked rhetorically, "What has concluded, that we might conclude in regard to it?" (p. 190). In science there are always new instruments, methods, and truths. Science is an open-ended process and there is no final once-and-for-all conclusion.

Hypotheses, Theories, and Laws are Falsifiable

The British philosopher Karl Popper (1902-1994) proposed that scientific hypotheses, theories, and laws are falsifiable; they have a test for wrongness (Popper, pp 40-44). Philip Kitcher states this same idea more succinctly, "Science can succeed only if it can fail" (p. 45). It is important to understand that ideas that seem to falsify a well-confirmed hypothesis are rightly met with skepticism. For example, in the early nineteenth century unexplained perturbations were observed in the orbit of Uranus. One possibility was that Isaac Newton's (1642-1726) law was failing at great distances. Another possibility, however, was that an unknown object was influencing the motion of Uranus. The perturbations in the orbit of Uranus were used as a basis for calculating the size and the position of an object that might cause such fluctuations. In this way, astronomers hoped to save Newton’s law while at the same time explaining the fluctuations in Uranus’s orbit. This is a good example of the introduction of an auxiliary hypothesis. The auxiliary hypothesis was that another object, as yet undiscovered, was influencing the orbit of Uranus. As a consequence of this auxiliary hypothesis, the planet Neptune was discovered. This auxiliary hypothesis could be tested in a way that was independent of the idea it was designed to save, a visual verification in this case. Auxiliary hypotheses that have an independent test can be useful and productive. Auxiliary hypotheses that do not have a test independent of the idea they are designed to save are termed *ad hoc*.

A different example of apparent falsification of a theory is that Newton's law of gravity could not fully account for the precession in Mercury's orbit about the Sun. This did not mean, however, that Newton's law was abandoned. Scientists value what works, so there is great inertia in giving up an idea that has proven useful and dependable. Albert Einstein's (1879-1955) general theory of relativity does fully account for the precessions observed in Mercury's orbit. Thus, Newton's law of gravity was shown to be a low-mass approximation of general relativity.

Conclusion

The final claim to objectivity in science is that it is a collective enterprise where any individual's views are subject to criticism by others (Popper, p. 44). Scientific methodologies are powerful because of their empirical ruthlessness. There is freedom of belief and speech in science, but not freedom of knowledge. One may, if one so chooses, believe that the Earth is at the center of our planetary system that the entire fossil record was created from one great worldwide flood, or that gaps in human knowledge about the natural world are evidence of the supernatural. If, however, you want your beliefs recognized as scientific knowledge you must be open to empirical tests. If your beliefs do not stand up to the empirical evidence, they will not be included in scientific texts. Indeed the intellectual community may not even take them seriously (cf. Rauch, pp. 116-117).

The methodological naturalism of science is often misunderstood and sometimes legally challenged by those who would like to wedge supernatural explanations and putative authoritative claims into science textbooks (Viney, 2007, p. 525). The body of knowledge associated with science that so many admire is next to meaningless without the methodologies that shape and temper them. Fortunately, many philosophers, scientists, citizens, and theologians representing diverse religions have testified in behalf of science as a process. The decision handed down by Judge John E. Jones the III in the Dover; Pennsylvania ID case sums up our discussion well. Citing trial testimony from well-known philosophers of science, Jones wrote, "Methodological naturalism is a 'ground rule' of science today which requires scientists to seek explanations in the world around us based upon what we can observe, test, replicate, and verify" (p. 65).

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