# Scientific Reasoning: Confirming Hypotheses

The **confirmation** of scientific hypotheses by evidence is a matter of inductive reasoning. Each new observation or experimental result serves as a premise which can make our conclusion (regarding the truth of the hypothesis) either more or less likely to be true. With this general background, it is important to keep the following key points in mind:

* A hypothesis is a proposed **explanation** that goes “beyond” what we already know. Because of this, we do not (initially) know whether a hypothesis is true. As we conduct experiments and observations, however, we can begin to figure this out.
* A hypothesis is **confirmed** by evidence that gives us some reason to believe that this hypothesis is true. The fact that some particular evidence confirms a hypothesis does NOT mean that we have good reason to believe the hypothesis, all things considered. In order to establish this, we often need a large amount of high quality evidence.
* Confirmation comes in **degrees**. If a hypothesis is strongly confirmed by evidence, then that evidence gives us very good reason to believe the hypothesis. If the evidence only weakly confirms the hypothesis, by contrast, this might mean we need to go gather more data. There are many intermediate degrees of confirmation.
* A well-confirmed hypothesis is sometimes referred to as a scientific **theory** (“The theory of relativity,” “The theory of continental drift,” “The theory of gravity,” and so on). This is *different* from the way we sometimes use the word “theory“ in other contexts, where “theory” means something like a “guess.”

**How Confirmation Works.** A hypothesis is confirmed by a given observation if and only if the following TWO criteria are met:

1. We don’t already know that the hypothesis is false. Once we know that a hypothesis is false, no further data can confirm it. So, for example, since we now know that the earth revolves around the sun, the observation that “it sure doesn’t feel like the earth is moving” does NOT confirm the hypothesis that “the earth really doesn’t move.”
2. The following inequality holds: “The probability that we would see these observations on the assumption that the hypothesis is true” is greater than “the probability we would see these observations on the assumption that some other hypothesis is true.” In other words: if this hypothesis really were true, we’d expect to see this sort of thing. On the other hand, if it were false, this would be much more surprising.

The basic point: What matters for confirmation is making **surprising** predictions that turn out to be true. A hypothesis is NOT confirmed by predicting things that we already expected.

## Empirical vs. Theoretical Hypotheses

An **empirical hypothesis** is a hypothesis whose truth or falsity can be directly observed. If we observe that the hypothesis is true, the hypothesis is very strongly confirmed. For example, suppose that we have the following explanandum: “My car has suddenly begun pulling to the left.” Here are some empirical hypotheses:

* Empirical Hypothesis 1: My left front tire is flat.
* Empirical Hypothesis 2: My left rear tire is flat.
* Empirical Hypothesis 3: The axel rod on my car is broken.

Determining which one of theses hypotheses (if any) is correct can be directly observed (either by me or by a mechanic). Once we have done these observations, we can strongly confirm one of the hypothesis, while falsifying the others. Of course, we can’t be *absolutely sure* of the truth of a hypothesis (perhaps I made a mistake in my observation, or maybe I’m dreaming). However, if two different mechanics tell me that my left rear tire is flat (and I think its flat, as well), I have *very good reason* to believe to believe that hypothesis 2 is the correct one, while hypotheses 1 and 3 are not.

Many hypotheses of scientific interest (including most of the important ones) are NOT empirical hypothesis, since they involve things (electrons, distant stars, viruses, the past, mental states) that CANNOT be directly observed. Hypotheses involving such unobservable entities or processes are called **theoretical hypotheses**. Theoretical hypotheses are confirmed or falsified by considering all of the evidence (as opposed to empirical hypotheses, which can essentially be confirmed or falsified by a single observation). The decision to adopt a theoretical hypothesis is a function of four interrelated factors:

1. Is the hypothesis **adequate**? That is, is it a good explanans for the explanandum that it was originally proposed to explain?
2. Is the hypothesis **internally coherent?** How “simple” is the hypothesis? Does the hypothesis require lots of “adjustment” to get it to fit the actual data (if so, that’s bad)?
3. Is the hypothesis **externally consistent**? How well does it fit with other, well-confirmed theories in different areas of science?
4. A good hypothesis should be **naturalistic**, and should ideally avoid attributing things such as desires, intentions, or beliefs to the natural world (so, no gods or demons).
5. Is the hypothesis **fruitful**? If this hypothesis were adopted, would it suggest new hypotheses that could be tested? If we knew the hypothesis were true, would this allow us to do things?

Hypothesis confirmation is often **comparative**—we want to know which hypothesis (of the two or more that have been proposed) does better on these criteria. This means we need to be careful about assuming that our current working hypothesis is the “true” one; instead, we might say “it’s closer to the truth than the others” or “it’s our best explanation right now, and should be assumed until we find something better.”

**Theoretical Hypotheses: An Example:** Suppose our explandandum is “The earth orbits the sun.” Let’s consider the following hypotheses:

* Theoretical hypothesis 1: There is an attractive force, gravity, that pulls massive objects like the earth and the sun together. [Since we cannot see gravity, this is a theoretical hypothesis, as opposed to an empirical one.]
* Theoretical hypothesis 2: Invisible demons are carrying the earth in a circle around the sun. [Again, we cannot observe the demons, so this a theoretical hypothesis.]

In this case, it is clear that Newton’s theory of gravitation (hypothesis 1) is superior to hypothesis 2. While both hypotheses “explain” the phenomenon, Newton’s theory is simpler (gravity is a force we already know about, while invisible demons would be something entirely new). It also fits better with the rest of physics, is more naturalistic, and is fruitful (since it allows us to predict how *other* heavenly bodies will move in response to gravitational forces). This doesn’t mean, of course, that Newton’s theory is entirely correct as a description of the universe. In fact, Einstein showed that Newton’s theory *wasn’t* correct, even though it worked well in certain sorts of settings (and quantum theory showed that Einstein wasn’t correct, though he was closer than Newton, and so on).

## Darwin and Paley: Evaluating Theoretical Hypotheses

To see how the evaluation of theoretical hypotheses works in practice, let’s consider a “real world” case from the history of science: the comparison of Darwin’s hypothesis of evolution by natural selection with William Paley’s hypothesis of divine creation of individual species. We’ll be considering only the evidence that was available to Darwin at the time that he wrote, with an eye toward showing *why* subsequent generations of biologists adopted his theory (and rejected Paley’s). (*Note:* This is NOT intended to survey the modern debate concerning whether “intelligent design” should be taught in schools. The emphasis here is on understanding the historical debate.)

**Background.** Perhaps the best-known debate concerning scientific hypotheses is the 19th century argument over the origin of species. The explanandum could be described as follows “Organisms have complex adaptations that allow them to flourish in their environments.” The two hypotheses of interest were:

* Hypothesis 1 (**Creationism**, defended by William Paley): “The first member(s) of each species was created by an intelligent designer. Species were specifically designed for the environments in which they live.”
* Hypothesis 2 (**Evolution by natural selection**, defended by Charles Darwin): “All organisms descended from a small number of ancestors. Adaptations are caused exclusively by the facts that (1) there is random variation among the traits of a population, (2) there is non-random selection amongst traits (i.e., organisms with certain traits are more likely to survive and reproduce), and (3) offspring inherit traits from their parents.”

Both of these hypotheses are theoretical rather than empirical, since we cannot *observe* the historical origins of the various species. So, we need to consider the criteria for assessing theoretical hypotheses just introduced.

**Adequacy.** The first (and most important) criterion is adequacy. A (very) rough way of looking at this: the hypothesis that explains the most facts “wins”. Some things that Darwin could explain that Paley could not include the following:

1. The fossil record showed gradual change, which Darwin’s theory definitely predicted. Paley’s theory was compatible with this (the creator *could* have done things this way), but his theory gave no reason to expect it.
2. There were many cases in which the experts disagreed on what counted as “members of the same species”. This was to be expected on Darwin’s theory, since species emerged slowly over time, and we would expect this sort of “gradualism.” On Paley’s theory, it was surprising, since each species was created entirely separately.
3. Many organisms have rudimentary organs that serve no apparent purpose. Again, Darwin’s theory predicted this (since these organs might be remnants of things that *did* matter to distant ancestors of the organism), while Paley’s did not (Why would the creator make useless organs?).
4. Non-native (or “invasive”) species are often more successful in an environment than native species are. This would be surprising if organisms were “custom-designed” for their environment, as Paley had argued. It’s exactly what we would expect on Darwin’s theory however.
5. Long-lasting geographical barriers (such as the Panama isthmus) often separate entirely different species, even if the environments (the oceans on either side of the canal) are almost identical (and could support the same species). If species were custom-designed (Paley), this would be very surprising, since there would be no *reason* for a creator to do that (why design two species for the same environment?). The random aspects of the evolutionary process, by contrast, would account for it.
6. Other facts: Darwin also discussed the structural similarities (in skeletal structure, etc.), the cross-species similarities between embryos and fetuses (mammalian embryos/fetuses have non-functional “gills”), all of which seemed difficult to explain if each species was designed independently, but which might be expected if natural selection was responsible (since natural selection always has to “work with what is already there,” and can’t design new organisms from the ground up). A

None of these predictions *falsified* Paley’s theory: after all, it is entirely possible that a creator might have wanted to design living things in this way for some (unknown) reason. However, Darwin argued that his theory, unlike Paley’s, provided a good *explanation* of why they were true. On Darwin’s theory, these were the sorts of things that one would *expect* to see.

**Internal coherence** means that the parts of a theory “fit together” and the hypothesis does not require “tinkering” to make it work correctly. Darwin’s theory was highly internally coherent. It required only a few, simple assumptions: “Organisms resemble their parents, but differ in small ways. The most fit organisms will reproduce at a higher rate than less fit organisms. ”Paley’s theory was not (as) internally coherent, and required many small “adjustments” to make it work OK. “The creator usually created the best organisms for each environment, but sometimes did not. The creator made the fossil record so that it looked like evolution was true, even though it wasn’t. The creator sometimes gave organisms rudimentary organs, even though these organs were useless.” So, while Paley’s theory seemed simple to people who were NOT biologists, those trying to apply it found that it required lots of (fairly unintuitive) claims about how the intelligent creator would behave.

A hypothesis that is **externally consistent** will fit with well-confirmed hypotheses in other areas of science. Darwin’s theory was highly externally consistent. It fit with recent discoveries in geology (e.g., rock formations suggesting the earth was much older than 6,000 years), physiology (e.g., the development of human and mammalian embryos), and zoology (e.g., the fact that zoologists often could not agree on what counted as a new “species”), and biogeography (e.g., which species were found in which geographic locations). Later, Darwin’s theory would fit well with developments in chemistry (e.g., studies of DNA). Paley’s theory either contradicted other well-confirmed hypotheses (e.g., in the case of geology) or strongly suggested that they were incorrect (e.g., in the case of physiology or zoology). It didn’t appear to be **naturalistic**, at least if the creator was identified with a divine figure.

A hypothesis **fruitful** to the degree that it opens up new areas for research, and suggests new hypotheses that can be tested. Darwin’s theory proved to very fruitful, even in the years immediately after his death. It quickly led to new hypothesis in paleontology (regarding the types of fossils that would be found) and eventually in genetics (regarding the existence of “genes” and DNA). In the twentieth century, it was central to the study of medicine (e.g., regarding the “evolution” of cancer cells, or of antibiotic-resistant pathogens) and many other areas. Paley’s hypothesis was not fruitful—if we were suddenly assured that Creationism were true, this would tell us almost nothing about genetics, medicine, or paleontology.

**CONCLUSION:** According to the criteria we have adopted, Darwin’s theoretical hypothesis was strongly confirmed by the evidence that he provided. This does NOT mean that Creationism is “falsified” (in fact, some philosophers of science have argued the theory is unfalsifiable, and thus might not qualify as “scientific” in the first place), but it does help explain why scientists have thought that there are good (inductive) reasons for preferring Darwin’s theory to Paley’s.

## Review Questions

Are the following claims true or false? Explain your answer.

1. A hypothesis should always be derived from the facts. That is, it should never go beyond what we already know.
2. If a hypothesis has an implication that is found to be false, the hypothesis still might be true.
3. If a hypothesis has an implication that is found to be true, the hypothesis still might be false.
4. The first step of the hypothetical method is to clearly identify the explanandum (or thing to be explained).
5. An example of an empirical hypothesis would be “magnetism and electricity are manifestations of the same fundamental force.”
6. A well-confirmed theoretical hypothesis might still turn out to be false.
7. Since we cannot never know for sure which hypothesis is correct, it is equally reasonable to believe in any hypothesis that has not been falsified.