# Scientific Arguments

Scientific reasoning a huge role in almost every part of our day-to-day lives. Among other things, the ability to understand and evaluate scientific arguments plays a huge (and ever-increasing) role in decisions about what we eat, which medical treatments we use, which products we buy, how we parent/exercise/shop, and even our beliefs on which political proposals are most likely to improve things (and which are most likely to make them worse). These arguments concern everything from physics (nuclear power, space travel), biology (genetically modified crops), psychology (parenting, “management” techniques), and economics, just to name a few different areas.

## The Basics

Logicians and philosophers of science (many of whom were scientists themselves!) have spent a lot of time thinking and writing about “how science works.” Not surprisingly, they don’t all agree on this. However, there are a number of key concepts which *most* of them agree are central to understanding scientific reasoning:

**Explanations: Brief Review.** As we discussed earlier in class, an **explanation** is a set of two or more statements, one or more of which (the explanans) are claimed to be the reason/cause of the other (the explanandum). In this sense, they resemble arguments (with premises and conclusions). However, unlike the conclusion of an argument, we already *know* that the explanandum is true. So, when Julie offers the explanation in the example below, she is trying to explain *why it is* that she didn’t do well on her math test. Of course, this explanation may or may not be the *correct* explanation—perhaps the real reason that Julie didn’t do well is because she didn’t attend class regularly, or something like that. For example:

* Explanans 1: Julie didn’t sleep well last night.
* Explanans 2: Julie has a hard time concentrating when she doesn’t sleep.
* Explanandum (what is to be explained): So, Julie did poorly on her math test today. (We already knew this was true—we are trying to figure out why it happened.)

**What is a (Scientific) Hypothesis?** There are many facts for which the explanation is not obvious:

1. My car did not start this morning, after having trouble earlier this week.
2. I went to a new seafood restaurant last night, and woke up with a strange rash this morning.
3. Barack Obama won the 2012 election.
4. The average surface temperature of the earth is higher now than it was 50 years ago.
5. Killing adult humans for fun is morally wrong.

In our attempts to explain these facts, we can propose tentative explanans, called **hypotheses:**

1. The battery on my car has finally died.
2. I am having an allergic reaction to shellfish.
3. Women, minorities, and younger voters turned out a higher rate than men, whites, and older voters.
4. Increased carbon dioxide emissions have caused a greenhouse effect, which is “trapping” heat near the earth.
5. It is wrong to deprive a person of a “future like ours.”

Among other things, scientific reasoning involves attempts to confirm or falsify various hypotheses (though science also involves activities such as measurement, which may not involve directly testing hypotheses). In many cases, scientists consider *multiple* hypotheses that might explain a given set of facts, and use experiments and observations to figure which hypothesis, if any, is the correct one. (As the above examples show, though, not all hypotheses involve scientific reasoning).

## The Hypothetical Method: Deduction and Induction

The **hypothetical method** is commonly used both in science and in everyday life. It has four steps, which involve both deductive and inductive reasoning. I’ve used Darwin’s theory of evolution by natural selection as an example here, since this is undoubtedly one of the scientific theories people are most familiar with, and which has featured in many arguments over the role of science in education and policy:

* **Step 1: Clearly identify the explanandum, or the fact that you want to explain.** Example: Organisms are generally well-suited for their environments. A sparrow’s wings allow it to fly quickly over short distances (and change direction rapidly to avoid predators), a penguin’s fins allow it swim, and a goose’s wings are ideal for long-distance flight.
* **Step 2: Formulate a hypothesis.** Example: Organisms have a common ancestor, but have been shaped into different species by natural selection. At some point in the distant past, there was a common ancestor of geese, sparrows, and penguins. The descendants of this common ancestor ended up living in different environments, with very different selective pressures.
* **Step 3: Deduce implications or predictions of the theory.** Example: If evolution via natural selection is true, the fossil record should show gradual change. In some general sense, bird fossils found in era B should be “Intermediate” between the older fossils of A and the younger fossils of C.
* **Step 4: Test the implications.** If the predictions are correct, the hypothesis is confirmed, which provides *some evidence* to think the hypothesis is true. This is the inductive part of the hypothetical method. Example: Go check to see whether this is in fact what the geological record shows.

When using the hypothetical method, there are a number of key points to keep in mind:

1. **You can’t deduce a hypothesis from the facts.** The deductive part of the hypothetical method involves deducing *predictions* from the *hypothesis.* It is important to remember that this does NOT work the other way around: one cannot simply deduce a hypothesis from one what has observed. This is because any worthwhile hypothesis must always go “beyond” what you already know, and suggest *additional* tests or experiments. For example, if a patient has lung cancer, a physician cannot simply assume “Oh, he or she must have been a smoker.” This would be a hypothesis, which would need to be tested further.
2. **The hypothetical method is often the *only* way of finding explanations.** Formulating a hypothesis and deducing implications (that you can then check) is the only way to “guide your search” for a true explanation. Without a hypothesis, you would have *no idea* of what sorts of facts might be relevant to explanation. This relates to the previous point: science does not precede simply by recording the facts and generalizing from them. Instead, scientists need to decide *ahead of time* which hypotheses they want to test, and then consider whether the evidence supports these hypothesis.
3. **Determining whether a hypothesis is FALSE is often much easier than determining whether it is TRUE.** If an application of the hypothetical method produces an incorrect prediction (as often happens), this means that either the hypothesis was false, or one of your other assumptions (e.g., concerning the accuracy of your test) was false.Even ONE false prediction is enough to do this. By contrast, it can often require *many* successful predictions (in a wide variety of situations) before we are willing to say a hypothesis is likely to be true, or that it is the *best* explanation for the phenomena in question.

## Falsification versus Confirmation

Point 3 (above) said two things: (1) If a hypothesis makes an incorrect prediction, we can be (deductively) certain that one of our assumptions was FALSE, and (2) if a hypothesis makes a correct prediction we DON’T know that it is true, even though this may provide (inductive) support for the hypothesis. So, there is an asymmetry between falsity (easy to establish) and truth (much harder to establish). So, for example, let’s suppose Bob and Belinda are roommates with Betty. Betty never goes out during the day, which puzzles Bob and Belinda. Bob and Belinda propose the following hypotheses to explain this fact:

* Bob’s Hypothesis: “Betty is a vampire.” Implications: “If we take Betty into sunlight, she will explode. She may or may not have hair lying around her room”
* Belinda’s Hypothesis: “Betty is a werewolf.” Implication: “Betty will have lots of loose hair laying around her room. She won’t explode in sunlight.”

Suppose that Bob drags Betty outside and she does NOT explode. Simultaneously, Belinda looks around Betty’s room, and does find lots of loose hair. The hypothetical method allows us to conclude that Bob’s hypothesis is FALSE. By contrast, we still can’t determine whether Belinda’s hypothesis is true. It is important to remember that there will always (always!) be hypotheses that are not considered. For example, perhaps Betty works a night shift at the local hospital, and sleeps during the day. However, because Bob and Belinda aren’t considering this hypothesis, they can’t test it.

## Hypothetical Reasoning in Science: An Example

Hypothetical reasoning plays a huge role in the history of science. One problem of historical interest concerns the fact “When observed from Earth, planets like Mars, Venus, Mercury, and Jupiter appear to wander around the sky—that is, they sometimes appear to move backwards. This is very different from the way stars appear to move.” Here are three historically important hypotheses:

**Hypothesis 1 (Aristotle): The planets orbit around a stationery earth in circular orbits.**

* Implication: The planets should NOT move backwards, but instead should always move in the “same direction” across the sky.
* Testing: The planets appear to move backwards, so the hypothesis is FALSFIED.

**Hypothesis 2 (Ptolemy): The planets orbits around the stationery earth in circular orbits but some circle back in small “epicycles.”**

* Implication: The planets will sometimes appear to move “backwards” across the sky.
* Testing: The hypothesis is NOT falsified, since the implications agree with what we observe.

**Hypothesis 3 (Copernicus): All of the planets orbit the sun, and the moon orbits the earth. The earth is not stationery.**

* Implications: From our perspective, it will sometimes appear as if planets “wander” backwards and forwards.
* Testing: This agrees with observation. So, the hypothesis is NOT falsified.

Our problem is that both Ptolemy’s hypothesis and Copernicus’s appear to “explain” the data. That is, both of the hypotheses can account for the fact that the planets appear to “wander” backward and forward through the night sky. What we need to do is figure out a **crucial experiment**. That is, we need to figure a particular experiment where Ptolemy’s hypothesis says that we should get one result, and Copernicus’s hypothesis says that we should get another result.

**Galileo’s Telescope.** Galileo, a proponent of Copernicus’s theory, built an early telescope, which allowed him to see things that earlier astronomers (such as Copernicus and Ptolemy) could not. This allowed him to carry out something like a crucial experiment to decide between Copernicus’s and Ptolemy’s hypotheses:

* Ptolemaic prediction: The earth is the center of the universe—everything orbits around it. So, observations through the telescope should NOT reveal moons orbiting other planets.
* Copernicus prediction: The earth is not the center of the universe, but it nevertheless has a moon orbiting around it. So, it is perfectly possible that other planets will have moons orbiting around them, which the telescope will enable us to see.

While observing Jupiter with his telescope, Galileo observed small “dots” that would pass across the face of the planet and then “disappear.” This happened at regular intervals, and Galileo realized that these were moons orbiting the planet, in sharp contrast to what the Ptolemaic theory would have us believe. Galileo was also able to make successful prediction about the “phases of Venus”—his theory, unlike Ptolemy’s, successfully predict which parts of Venus would be lit up by the sun at particular times. He concluded that Copernicus was right, and that the Earth was NOT the center of the universe.

**“Saving” Falsified Hypotheses.** Galileo’s observations are now widely accepted as evidence in favor of the Copernican theory. However, this was not so at the time. Instead, influential religious figures argued that observations through the telescope could not be trusted (perhaps because of supernatural forces were trying to “trick us” in rejecting an earth-centered view of the universe.).

## Review Questions

For each of the following explananda (i.e., things to explain), propose at least three potential hypotheses. Then, state an implication of each hypothesis that would allow you test your hypothesis.

1. On your calendar, you have marked down “meeting with biology lab partner Tuesday at 4:00 PM at cafeteria.” You go to the cafeteria, and your lab partner is not there.
2. You have a pet dog, Boon, that almost always greets you at the door when you come home. One day, Boon does not greet you.
3. Your significant other, Sam, used to come meet you for dinner nearly every evening. For the last month, however, Sam has been “working late,” and only meets you for dinner once or twice a week.