The scientific method

How the scientific method is used to test a hypothesis.

Introduction

A biology investigation usually starts with an observation—that is, something that catches the biologist's attention. For instance, a cancer biologist might notice that a certain kind of cancer can't be treated with chemotherapy and wonder why this is the case. A marine ecologist, seeing that the coral reefs of her field sites are bleaching—turning white—might set out to understand why.

How do biologists follow up on these observations? How can *you* follow up on your own observations of the natural world? In this article, we'll walk through the **scientific method**, a logical problem-solving approach used by biologists and many other scientists.

The scientific method

At the core of biology and other sciences lies a problem-solving approach called the scientific method. The *scientific method* has five basic steps, plus one feedback step:

1. Make an observation.
2. Ask a question.
3. Form a **hypothesis**, or testable explanation.
4. Make a prediction based on the hypothesis.
5. Test the prediction.
6. Iterate: use the results to make new hypotheses or predictions.

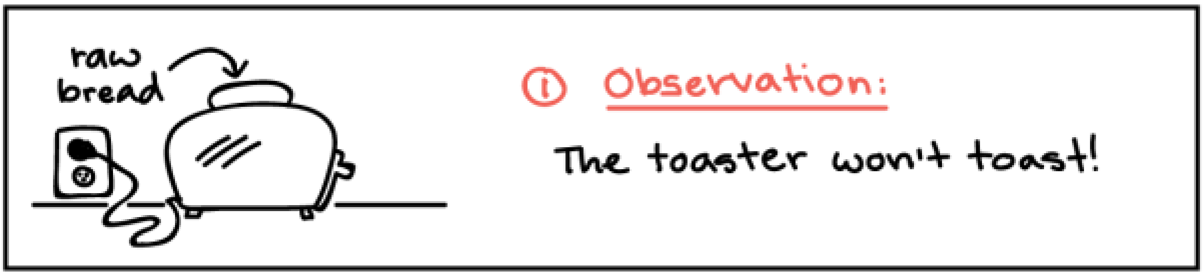
The scientific method is used in all sciences—including chemistry, physics, geology, and psychology. The scientists in these fields ask different questions and perform different tests. However, they use the same core approach to find answers that are logical and supported by evidence.

Scientific method example: Failure to toast

Let's build some intuition for the scientific method by applying its steps to a practical problem from everyday life.

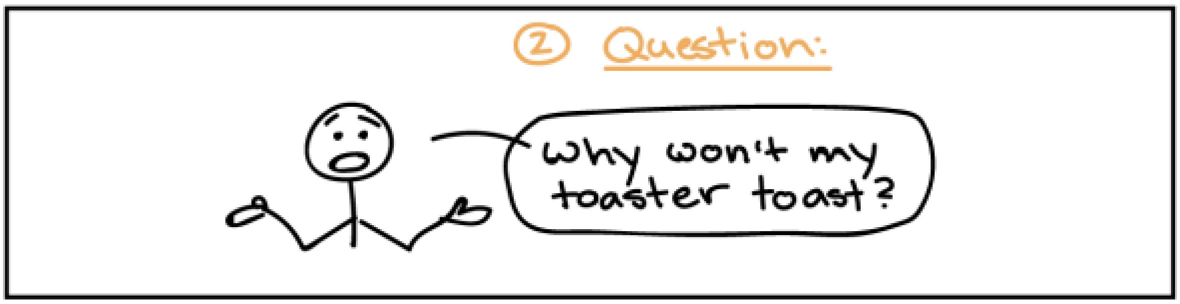
1. *Make an observation.*

Let's suppose that you get two slices of bread, put them into the toaster, and press the button. However, your bread does not toast.



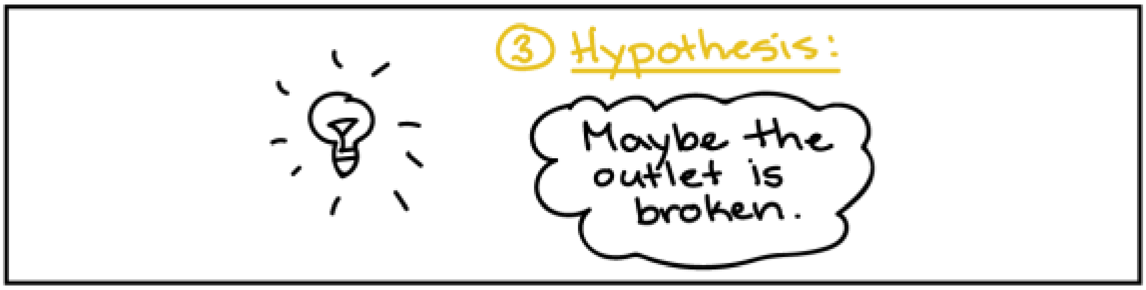
1. Observation: the toaster won't toast.
2. *Ask a question.*

Why didn't my bread get toasted?



2. Question: Why won't my toaster toast?
3. *Propose a hypothesis.*

A *hypothesis* is a potential answer to the question, one that can somehow be tested. For example, our hypothesis in this case could be that the toast didn't toast because the electrical outlet is broken.



3. Hypothesis: Maybe the outlet is broken.

This hypothesis is not necessarily the right explanation. Instead, it's a possible explanation that we can test to see if it is likely correct, or if we need to make a new hypothesis.

A hypothesis must be testable and falsifiable in order to be valid. For example, “Botticelli’s Birth of Venus is beautiful" is not a good hypothesis, because there is no experiment that could test this statement and show it to be false.

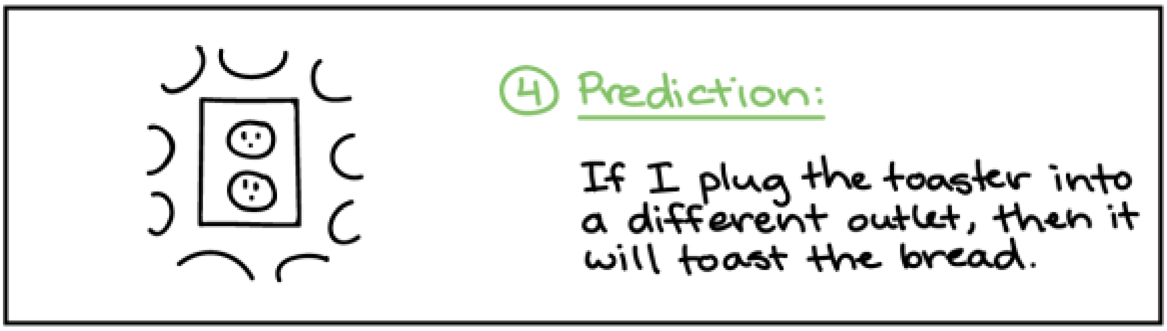
However, "People find Boticelli's Birth of Venus to be beautiful" *is* falsifiable, because you could conduct an experiment in which you asked many people from different walks of life whether they thought the painting was beautiful. Notice that how we phrase a hypothesis can have a big impact on whether it is valid or not.

This question comes up a lot, particularly in reference to things like Darwin's theory of evolution. A theory is different from a hypothesis, though they're certainly related. A hypothesis is a potential answer to a relatively small, specific question. A theory, on the other hand, addresses a broader question and is supported by a large amount of data from multiple sources1,2^{1,2}1,2 start superscript, 1, comma, 2, end superscript.

For example, "The toaster won't toast because the electrical outlet is broken" is a hypothesis, whereas "Electrical appliances need a source of electricity in order to run" is closer to a theory.

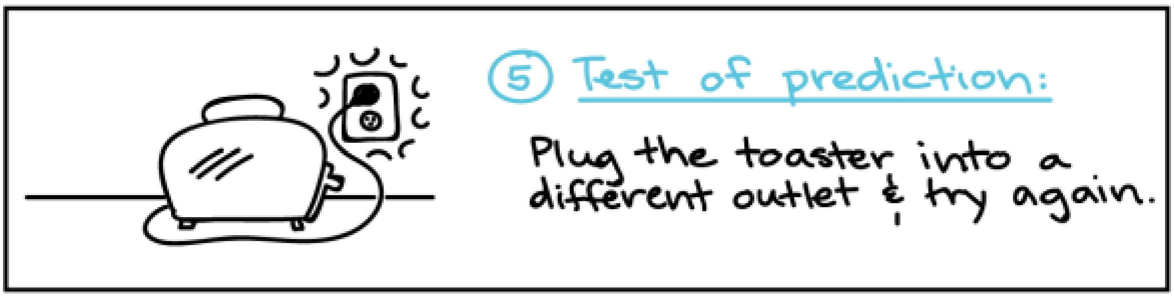
4. *Make predictions.*

A prediction is an outcome we'd expect to see if the hypothesis is correct. In this case, we might predict that if the electrical outlet is broken, then plugging the toaster into a different outlet should fix the problem.



4. Prediction: If I plug the toaster into a different outlet, then it will toast the bread.
5. *Test the predictions.*

To test the hypothesis, we need to make an observation or perform an experiment associated with the prediction. For instance, in this case, we would plug the toaster into a different outlet and see if it toasts.



5. Test of prediction: Plug the toaster into a different outlet and try again.

- If the toaster does toast, then the hypothesis is supported—likely correct.
- If the toaster doesn't toast, then the hypothesis is not supported—likely wrong.

The results of a test may either support or contradict—oppose—a hypothesis. Results that support a hypothesis can't conclusively prove that it's correct, but they do mean it's likely to be correct. On the other hand, if results contradict a hypothesis, that hypothesis is probably not correct. Unless there was a flaw in the test—a possibility we should always consider—a contradictory result means that we can discard the hypothesis and look for a new one.

Why is it that we can't conclusively prove a hypothesis? And can we actually disprove a hypothesis?

One key distinction here is between what's logically possible and what's practically possible. *Logically* speaking, it's impossible to prove a hypothesis, but possible to disprove one. *Practically* speaking, it's challenging to either prove or disprove a hypothesis beyond the slightest doubt.

Logical possibility

As an example, suppose we have the hypothesis that all apples are red, and we test this hypothesis by examining a group of ten apples and seeing what color they are. If all ten apples are red, our hypothesis is supported, but it's not proven: if we looked at more apples, some of them might turn out to be green. On the other hand, if one of our ten apples is green, we have—in a world of perfect information and no error—disproven our hypothesis.

Practical possibility

Practically speaking—"in real life"—it's still impossible to prove a hypothesis since it's not even logically possible to prove a hypothesis. However, in real life scenarios, it also becomes difficult to disprove a hypothesis beyond any imaginable doubt.

For example, suppose that we examine our apples in the scenario above and find that one of them is green. If the green apple is *bona fide*, the hypothesis cannot be correct. However, it's possible that the apple is not actually green, in the sense we care about, and that we classified it as a green apple due to an error or a wrong assumption. For example, perhaps the green apple is a decorative apple that someone painted. Or maybe it's a red apple covered with green mold, which makes it look green on first examination.

Building a body of evidence

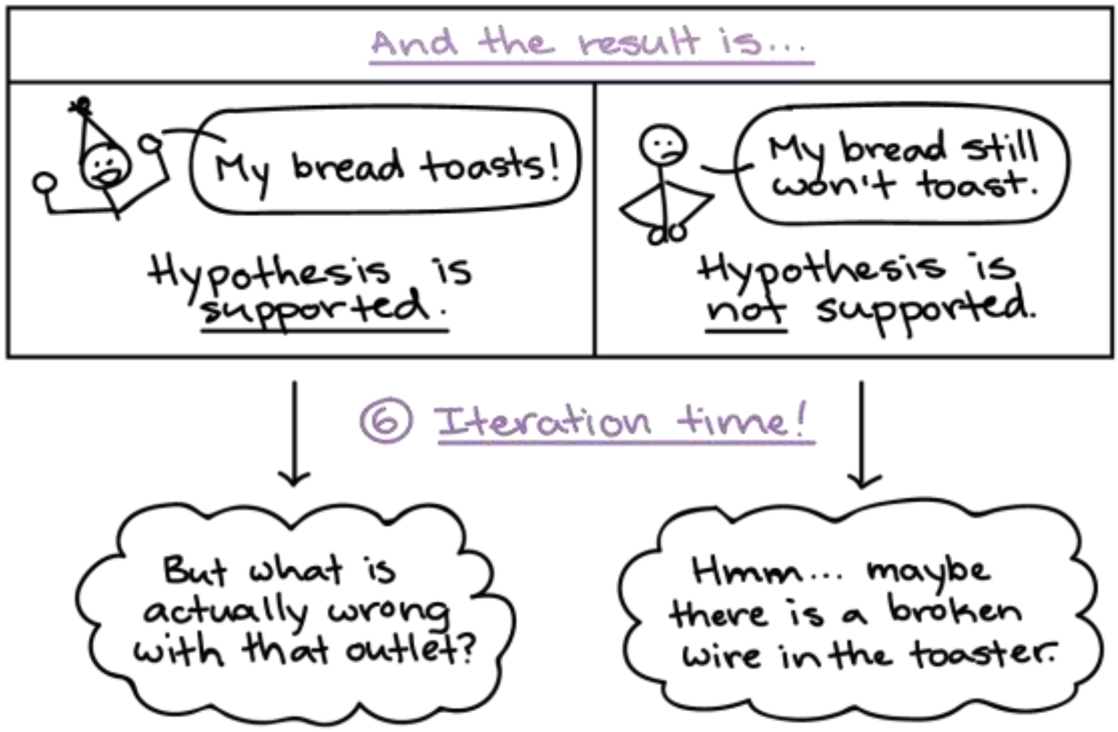
In a sense, we can never conclusively disprove the hypothesis that all apples are red in the real world because we can't exclude the tiny possibility of some kind of error, bad assumption, or bizarre coincidence.

However, suppose that we carefully investigate every alternative explanation we can think of—painted apples, moldy apples, etc.—and don't find support for any of them. In addition, let's say we repeat our experiment by looking at a much larger number of apples, and we find a consistent fraction of green ones. Additionally, people on neighboring farms report that they routinely see green apples as well.

In this case, although our hypothesis that all apples are red may not be disproven beyond all imaginable doubt, it is so strongly contradicted as to be effectively disproven. In other words, no one is likely to consider it correct, design experiments around it, or base assumptions on it.
Acknowledgements: *The apple example of hypothesis testing comes from KA Guardian Andrew M., who used it in an explanation in the comments section of this article. Many thanks to Andrew M. and other readers for their thoughtful discussion of hypotheses, proof, and disproof, which led to the revision and expansion of this section.*

6. *Iterate.*

The last step of the scientific method is to reflect on our results and use them to guide our next steps.



And the result is:

Left panel: My bread toasts! Hypothesis is supported. Right panel: My bread still won't toast. Hypothesis is not supported.

6. Iteration time!

Left panel (in case of hypothesis being supported): But what is actually wrong with the outlet? Right panel (in case of hypothesis not being supported): Hmm...maybe there is a broken wire in the toaster.

- If the hypothesis was supported, we might do additional tests to confirm it, or revise it to be more specific. For instance, we might investigate why the outlet is broken.
- If the hypothesis was not supported, we would come up with a new hypothesis. For instance, the next hypothesis might be that there's a broken wire in the toaster.

In most cases, the scientific method is an **iterative** process. In other words, it's a cycle rather than a straight line. The result of one go-round becomes feedback that improves the next round of question asking.