SCIENTIFIC METHOD: A BRIEF INTRODUCTION

"If you want to find out anything from the theoretical physicists about the methods they use, I advise you to stick closely to one principle: don't listen to their words, fix your attention on their deeds. To him who is a discoverer in this field the products of his imagination appear so necessary and natural that he regards them, and would like to have them regarded by others, not as creations of thought but as given realities." (A. Einstein, "On the Methods of Theoretical Physics")

In this lecture, we'll be talking about **scientific method**—that is, the process by which scientists accept or reject scientific theories. While this is often presented to students (especially in K-12 schools) as a straightforward process of formulating and testing hypotheses, the nature of the scientific method has itself been a matter of fierce debate among scientists, historians, and philosophers of science. Ideas about method have changed over time, and lively debates (with real consequences!) continue to this day. To make things even tougher, the methods that scientists *say* that they are following often don't match what is actually being done. The major questions we'll be answering in this lesson include:

1. What does it mean for the scientific community to *accept* a theory, as opposed to merely *use* it, or *pursue* it?
2. What is the difference between the *context of discovery* and the *context of justification?* And what does this have to do with the scientific method?
3. What's wrong with the "naïve" version of the scientific method usually taught in K-12 schools?

BASIC IDEAS: THEORIES AND MOSASICS

Before diving into our exploration of the scientific method, it will help to begin with a few definitions clarifying how key terms are going to be used (some of which we talked about last time):

A **scientific theory** is just a set of statements (or claims, or propositions) about the way the world is. Well-known scientific theories include Newton's theory of gravitation, Einstein's theory of General Relativity, the theory of evolution via natural selection, and so on. Importantly, saying something is a "scientific theory" does NOT mean "it is just a theory" (in the sense of being uncertain about whether it is true or false). Scientists can have various attitudes about theories:

- A scientific theory is **accepted** if the scientific community of the day believes it is the *best available description of reality that is available to them.* They don't necessarily need to think its perfect (after all, much of their time is spent improving and expanding it). However, it is closer to describing reality than anything other theory on offer. Some currently accepted theories include the "germ theory of disease" (in medicine), the theory of evolution via natural selection (in biology), the "Big Bang" theory in cosmology, and the "standard model" in particle physics.
- A scientific theory is **used** if the scientific community believes it is still useful for some practical purposes, *regardless of whether it is accepted as an accurate description of reality.* In physics, the usual example is Newtonian mechanics (which we KNOW is false, but which is really, really useful in many areas of engineering). This category might also include many theories in psychology, economics, etc.
- A scientific theory is **pursued** just in the case the scientific community thinks it is worthy of further elaboration, *even if it isn't accepted or even useful (in its current form).* There are LOTS of examples of theories that fall into this camp, including well-known ideas such as "String Theory" (in physics) or ideas about "alternative medicine."

At certain points during the history of science, a single theory has dominated others within its in discipline, in the sense that was the only accepted theory, the only used theory, and the only pursued theory (e.g., this was the case with Aristotle's ideas for roughly a thousand years, and Newton's theory for maybe 200 years). However, it is also pretty common to have cases where these three categories diverge—i.e., the community of scientists "accepts" the picture of reality provided by a certain theory, but continues to use theories that contradict this picture (because they are useful in certain contexts) and pursue possible alternatives to it.

The **scientific mosaic** is just the set of theories that are accepted at a given time by the scientific community (such as textbook authors and faculty at big universities). 600 years ago these theories were mostly based on the work of Aristotle (e.g., Earth-centered astronomy, the humoral theory of medicine, Aristotelian logic, and even theology). Around 300 years ago, the mosaic had changed to include Newtonian mechanics and calculus (though it still including humoral medicine and "natural theology"). The contemporary mosaic includes, among many other things, Einstein's theory of General Relativity, Quantum mechanics, Darwin's theory of evolution by natural selection, and so on.

Question: Can you give examples of theories that are (1) accepted by the scientific community, (2) used but not accepted, (3) pursued, even though they aren't currently useful/accepted?

WHAT IS THE SCIENTIFIC METHOD?

For the purposes of this class, we'll define the **scientific method** is a *rule* for theory acceptance or non-acceptance. That is, we apply the scientific method to tell us whether we should move a particular theory into the "accepted" category. While this seems simple enough, it is easy to confuse this with other, related notions:

- Simple examples of scientific methods would be "Accept whichever theory is the simplest," or "Accept whichever theory makes the most successful predictions and fewest failed predictions," "Accept any theory where $p > .05$" or even "Accept whichever theory is most popular with funding agencies". (These last two are especially bad ideas, but are unfortunately part of real science.)
- The scientific method does NOT tell us anything about good "research methods" or about the process of "thinking like a scientist." In fact, according to most statements of the scientific method, it is *completely irrelevant* how you came up with your theory (you had a dream! You found it in an old book! Aliens told you!). The scientific method just takes your end result and tells you whether it should be accepted or not.
- The scientific method that is (actually) accepted by the scientific community of a time often doesn't match up with scientist's (or philosopher's) explicit statements of their **methodologies.** So, for example, scientist-philosophers like Galileo, Descartes, Newton, Darwin, Einstein all had their own ideas of what *should* be the criteria for theory acceptance/rejection. However, looking back, it seems pretty clear that these statements of methodology did NOT always accurately capture the process by which their own theories were accepted or rejected by their peers in the scientific community.

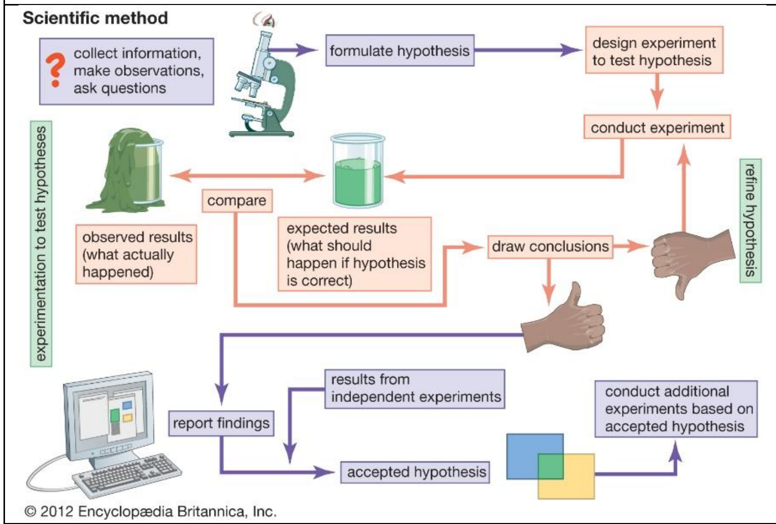
When we ask questions like "What is the scientific method?" we are thus asking questions that belong to what the philosopher of science Hans Reichenbach called the **context of justification** (What makes scientists *justified* in accepting one scientific theory? What role does empirical evidence play? Other factors?) rather than what he called the **context of discovery** (How was a theory discovered? What techniques were used? Where did the idea come from?).

One way of thinking about our question for today is as follows: **Is there any *unchanging* scientific method that determines how the scientific mosaic changes over time?** If there is, then the *reason* we see different theories enter/leave the mosaic might simply be because we have better evidence than we used to (for example, we've just done more experiments!). However, if the scientific method *itself* changes with the mosaic, this might be more worrisome, since it would suggest that, along with changes in scientific theories over time, there are ALSO changes in the criteria by which these theories are accepted or rejected.

Question: Try to come up with your OWN definition of the scientific method. Now, double-check to see whether it meets the requirements above—that is, does your definition explicitly say when theories should be accepted?

WHAT'S WRONG WITH THE "NAIVE" PICTURE OF THE SCIENTIFIC METHOD?

In introductory science textbooks (at both the high-school and college-level), students are taught the following picture of the scientific method, which is often attributed to Francis Bacon or his contemporaries in 17th century Britain. While there are valuable things about this picture, it also leaves out quite a bit.

<table>
<tr><th>The Naïve Picture</th><th>Three Problems With The Naïve Picture</th></tr>
<tr><td>
</td><td>1. This isn't a method at all, in the sense we've defined! It doesn't actually tell us anything about when the evidence we've collected is good enough for us to accept a theory (or conversely, when the evidence is sufficient to reject it).
2. This failure to discuss acceptance can be a problem if students come to (falsely) believe that the scientific method will lead unerringly to true theories. This isn't true (ask any scientist!). When these students discover this later in life (e.g., from climate science skeptics or anti-vaccination campaigners) it sometimes can lead them to reject science altogether.
3. This picture also conflates two different issues:(a) the processes by which individual scientists or research groups generate and test hypotheses (here, the worry is that this picture is far too simple) and (b) how the scientific community as a whole decides to accept/reject hypotheses.</td></tr>
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At best, this is a partial picture of how experiments might contribute to the acceptance or rejection of a hypothesis (but which doesn't actually talk about criteria for acceptance or rejection!). While a full discussion of the issues with the "naïve" picture of the scientific method are beyond the scope of this talk, it's an important example of the connection between philosophy, history, and science. The *reason* that this is taught to students seems to have more to do with textbook authors' (often unexamined) beliefs about the history and philosophy of science than with any study of what scientists (either now or historically) actually do.

Question: Is there a better way of teaching students "how to do science" (besides having them memorize the picture above)?