THE SCIENTIFIC METHOD

A. What is science? What isn't it? What things do we need in order to be scientists?
B. How to generate hypotheses
C. Occam's razor
D. Testing hypotheses: the role of falsification
E. How do we recognize truth?
F. Is maximizing truth always the goal of science?

A. What is science? First—what *isn't* it?

What stuff do you need to be a scientist?

Seriously though:

Science is the systematic process of falsifying possible explanations for observed patterns, until the least refuted hypothesis remains standing.

Hypothesis: a tentative explanation put forth to account for an observed phenomenon.

- Multiple hypotheses should be proposed whenever possible
- Hypotheses must be testable
- Hypotheses can be eliminated (disproven, falsified) but never confirmed with absolute certainty

What are some hypotheses that we can come up with now, on the spur of the moment?

An hypothesis: dinosaurs went extinct because they got too big

Is this a good hypothesis? Why or why not?

Come up with hypotheses to explain: Why giraffes have long necks.

And: what limits population size in *Eleutherodactylus coquí* (a tropical forest frog)?

Already known about this species:

- Lives in mid-elevation rainforests in Puerto Rico
- Nocturnal
- Forage for insects on the ground, or within three meters of the ground
- Males are territorial, and call from sites on leaves or tree trunks
- Frogs of both sexes are discriminating in their selection of nest and retreat sites. Retreat sites are defended by both sexes
- Nest sites are rolled leaves or leaf axils on or near the ground, and eggs are guarded by males.
- Intruders to nest sites eat pre-existing eggs and may usurp those sites.

Hypothesis? Predictions of the hypothesis? How to test the hypothesis?

Why do we care about the coqui?

Back to the scientific process, put another way

1. Observe a pattern that you would like to explain
2. Devise alternate hypotheses that could explain that pattern
3. Make predictions based on each of these hypotheses
4. Create tests with which to discriminate between the hypotheses (i.e. try to falsify each of the hypotheses)
5. As the data come in, rethink the remaining hypotheses or possibilities, and start the cycle again.
   (From Platt, J. R. 1964. Strong inference. Science 146 (3642): 347-353.)

B. Hypothesis generation in ecology

1. The researcher relies on observation, looks for pattern in nature, tries to sift through and interpret what she sees.
2. She brings together those first, empirical observations, and posits multiple hypotheses (induction).
   Often, the hypotheses are not only a result of preliminary observations, but are also informed by existing theory (this use of theory to generate a more precise or informed hypothesis is an example of deduction).
3. Having formulated several hypotheses, she deduces predictions of those hypotheses, which can be tested with experimentation and/or further observation (deduction).

The role of creativity in science

"The formulation of a problem is often more essential than its solution."
-Albert Einstein

Nature is incredibly complex, and we must simplify what is out there, to some degree, to have any chance of explaining individual pieces of it. Figuring out what to ask is a critical, difficult and creative part of the scientific process.

Generating alternative hypotheses is also a creative process. As is identifying how best to test the hypotheses: experimental design can be both creative and innovative.

C. Occam's Razor

Synonyms: Ockham's razor, (law of) parsimony

Definition: all else being equal, simpler explanations are preferable to more complex ones. Put another way: in choosing between two hypotheses that might explain a pattern, if all else is equal, the simpler one is preferred.

Important note: Occam's razor is not falsified when more complex explanations turn out to be true. Complexity evolves in nature, just as conspiracies are sometimes played out in the political arena.

D. Testing hypotheses: the role of falsification

Scientific ideas are tested by generating multiple possible hypotheses, coming up with predictions for each of them, and then designing tests/thought experiments by which we can falsify the hypotheses.

We test hypotheses in order to refute them, not to try to support them.

Thus, good scientists are both always trying to falsify their own, favorite hypotheses, and also exposing those hypotheses to the criticism of other smart people, who may see flaws that they cannot.

Why falsification? Why not verification?

Hypothesis: all crows are black

What would it look like to try to verify this hypothesis? To try to falsify it?

The discovery of echolocation in bats

In 1793, the Italian Lorenzo Spallanzani observed that owls become nearly helpless and unable to fly in a totally darkened room. Bats, on the other hand, did not. He hypothesized that bats are using sound to get around. The only alternative, in his view, was that they were using light to navigate.

So he blinded them, and tested the vision hypothesis. They could still fly when blind. Then he tested bats' abilities against one another, when they had filled vs. unfilled tubes in their ears. With plugged tubes, the bats crashed into things; with open tubes, the bats did fine.

Under what circumstances might the "least refuted hypothesis" be untrue?

The hair hypothesis…

When science is left to fallible apes:

The scientific method works because it stresses testability of hypotheses and predictions. Thus, even though we are all biased observers of the universe, informed by our own personal histories and ideas about the world, our scientific findings should be replicable by another, differently biased human being. Thus, while all scientists will always be biased, science in its purest form aims to escape bias.

Our goal is therefore carefully designed and implemented experiments that yield quantitative & replicable, rather than qualitative and hard to replicate, results. However: interpretation is part of science, and this is, by definition, biased. Thus, we have to admit that much of our science is informed by intuition, experience, judgment, and even luck.

E. How do we know something is true?

1. Question everything. Don't trust authorities, especially if they tell you to trust them because they're authorities on the subject. Always remain a skeptic.
2. Falsify, falsify, falsify.
3. Design tests that allow you to control for variables that you are not testing (what does it mean to control for a variable?)
4. Never stop the cycle of questioning and attempting to falsify. Theories last not because they are supported, but because they are least refuted. At some point, we come to believe that our inability to falsify a hypothesis demonstrates its truth, but even then, the lesson of Newtonian physics should stay with us.

(What is the lesson of Newtonian physics?)

F. Is maximizing truth necessarily the goal in science?

What is the trade-off between truth (accuracy of scientific results) and generality (predictive power) in science?