Chapter 1b: Exploring Life (section 1.5)

Important Point:

If you are having trouble understanding lecture material:

Try reading your text before attending lectures.

And take the time to read it well!

What is Science?

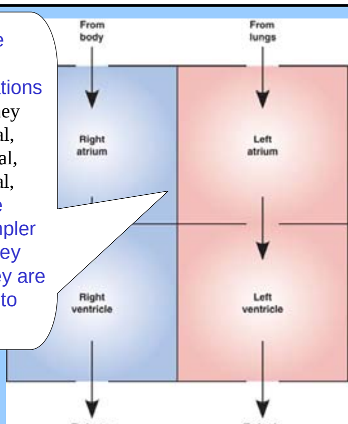
- "...science is simply common sense at its best; that is, rigidly accurate in observation and merciless to fallacy in logic." Thomas Henry Huxley, 1880
- "Scientists are critical realists." John Polkinghorne
- "Science is properly described as 'organized skepticism,' a realm in which nothing is to be accepted without question." Philip W. Anderson
- …nevertheless, and probably quite accurately, Margaret Wertheim replies with: "Science has always had a huge component of faith."
- This latter statement reflects the idea that ultimately not everything (nothing?) can be proven to 100% confidence; A good scientist nevertheless allows that even those things she accepts on faith could very well be incorrect

Science, A Few More Ideas

- "…scientists are not a select few intelligent enough to think in terms of 'broad sweeping theoretical laws and principles.' Instead, scientists are people specifically trained to build models that incorporate theoretical assumptions and empirical evidence. Working with models is essential to the performance of their daily work; it allows them to construct arguments and to collect data." Peter Imhof
- "Science is [best] understood by observing it than by trying to create a precise definition. The word *science* is derived from a Latin verb meaning 'to know.' Science is a way of knowing. It emerges from our curiosity about ourselves, the world, and the universe. Striving to understand seems to be one of our basic drives. At the heart of science are people asking questions about nature and believing that those questions are answerable." your text (older edition)
- "At the heart of science is **Inquiry**, a search for information and explanation, often focusing on specific questions." Campbell and Reece (2005, p. 19)

A Scientific Model

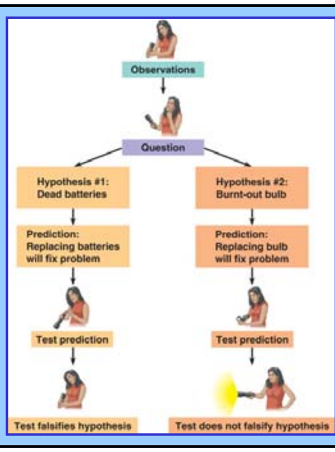
Models are abstract representations of ideas; they can be visual, mathematical, experimental, etc., but are always simpler than the they system they are purporting to model



Doing Science

- **Doing science involves:**
  - Asking good questions
  - Coming up with good, plausible answers (a.k.a., hypotheses)
  - Testing these hypotheses robustly, unambiguously, and honestly (the latter from the point of view of both yourself and that of others)
- "Science is a creative human endeavor that involves asking questions, making observations, developing explanatory hypotheses, and testing those hypotheses." your lab text
- It is "important for you to learn, by example and by practice, how the process of science works." your text
- "Anyone going into biology expecting to find the sorts of exceptionless laws that characterize physics will be sorely disappointed." Ernst Mayr

Doing Science



Time-Wasting Avoidance

- Science is a means of timing-wasting avoidance
- Doing science poorly (or not doing science at all) results in failing to answer questions efficiently
- Doing science poorly can result in wasting other's time (with poorly thought out hypotheses or results)
- The cost of wasting the time of others is ostracism—nobody wants to have their time wasted by incompetent boobs!
- Nevertheless, often there is a fine line between doing difficult science and wasting time—this is one reason the easy-to-solve problems tend to be solved sooner
- The "open-mindedness" that non-scientists often feel comes from lacking a well-developed compunction to answer hard questions rigorously (i.e., robustly, unambiguously, and honestly)

Questions Addressed

- What questions do scientists tend to address?
- More often than not the questions that are addressed first are those perceived to be both potentially fruitful and less difficult to answer
- For some questions science is willing to invest enormous amounts of resources (curing cancer, creating weapons of mass destruction during national military emergencies, etc.)
- For other questions, science (or, more precisely, funding agencies) are unwilling to invest many if any resources
- The basic questions come down to:
- Is the endpoint worthwhile?
- Are the resources necessary to solve the problem in excess of the perceived worth?
- Is the endpoint likely to be reached?

Questions Addressed

- Is the endpoint worthwhile?
- Are the resources necessary to solve the problem in excess of the perceived worth?
- Is the endpoint likely to be reached?

- For conservative, applied research, using established techniques, the answers generally are yes, yes, and yes (even when the scientific questions aren't terribly interesting)
- For speculative, basic, or extremely difficult research, the answers can be no, no, no
- Ultimately whether a question is pursued is a function of the amount of resources a society is willing to devote to science
- The consequence is that science does not always work toward its own goals with the efficiency it (or we) would prefer
- Wild card: questions (& means to answering questions) that are interesting in their own right

Succeeding in Science

- "Success in science is rewarded with attention. You gain full membership in the scientific community only by receiving the attention of your fellow scientists. Earning this attention 'income' is a prime motive for becoming a scientist and for practicing science. In order to maximize this income, you have to employ your own attention in the most productive way. It does not pay to find things out anew that have been discovered already. Nor is reinvention rewarding in terms of the attention paid. It pays to pay attention to the work done by others." Georg Franck
- In school, doing science well is rewarded with good grades in science class—the same skills that allow one to do science well will allow one to succeed in biology class: learning, understanding, synthesis, an ability to communicate your thoughts well, etc.

Asking Good Questions

- **Asking Good Questions**
- Forming Hypotheses
- Testing Hypotheses

- "Items investigated must be well defined, measurable, and controllable. The questions should be reasonable and consistent with existing bodies of knowledge. [Individuals] have a variety of ways to exclude wild speculations." your lab text
- A good scientific question is one that may be answered through experiment, observation, or logical inference that is built upon previous experimentation or observation
- Beware of direct correlations vs. indirect correlations (cause and effect vs. "effect and effect")
- Questions are also judged on the worth one or many perceive to be associated with successfully answering that question

Good vs. Bad Questions

- "Does exposure to ultraviolet radiation cause increased risk of skin cancer?"
- "Does good nutrition lead to increased intelligence?"
- "Why do cacti have spines?"
- "Was the malignant tumor found in the lungs of a 70-year-old man caused by his 45-year habit of smoking cigarettes?"
- Do good study habits result in good grades in science classes?
- Though these are all good questions, they are not necessarily easy to answer, however...
- Was Lee Harvey Oswald possessed by demons?
- Bad question:
- How do we define "demon"?
- How do we determine whether L.H.O. was possessed by one?

Forming Hypotheses

- Asking Good Questions
- **Forming Hypotheses**
- Testing Hypotheses

- "A hypothesis is a tentative answer to a well-framed question—an explantion on trial. It is usually an educated postulate, based on past experience and the available data of discovery science." Campbell & Reece (2005), p. 20
- "A hypothesis tentatively explains something observed." your lab text
- It is a proposed answer to a scientific question

"Good" Hypotheses

- Asking Good Questions
- **Forming Hypotheses**
- Testing Hypotheses

- A good hypothesis satisfies the following criteria:
- It supplies a testable mechanism
- It is not unnecessarily complicated (Ocham's razor)
- It conforms with existing knowledge
- It is falsifiable
- If something cannot be demonstrated to be *incorrect* then it cannot be demonstrated to be *correct*
- Hypotheses tend to gather favor if they could be but haven't been demonstrated to be incorrect
- "The test of a hypothesis may include experimentation, additional observations, or the synthesis of information from a variety of sources." your lab text

More on Hypotheses

- **Keep in mind that:**
- Hypotheses represent possible causes
- They reflect past experience with similar questions
- Multiple hypothesis should be proposed if possible
- Hypotheses should be testable via the *hypothetico-deductive* approach
- Hypotheses can be eliminated
- But hypotheses cannot be confirmed with absolute certainty
- Note that in practice hypotheses are a dime a dozen—easy to propose, difficult to prove
- Also, very few are sufficiently comprehensive nor stand up sufficiently to the test of time and experimentation to achieve the status of a *theory*

Qualitative Data

"The term data implies numbers to many people. But some data are *qualitative*, often in the form of recorded descriptions rather than numerical measurements." Campbell & Reece (2005, p. 19)

Scientific Theories

- A hypothesis becomes a theory following lots of testing (i.e., attempted falsifications), all of which fail to disprove the hypothesis
- An important aspect of this testing is that it is done by more than one (ideally by many) groups using more than one (ideally many) independent techniques
- In other words, a theory is a *very* robustly supported hypothesis
- Since, by definition, a theory has gone through considerable criticism and attempted falsifications, it is very unlikely that you or me or anyone we know or admire is going to successfully demonstrate that a well-established theory is false
- E.g., Darwin's *Theory* of Evolution (which in lay language we would describe as a *fact*)

Scientific Theories

- What is a theory and how is it different from a hypothesis or from mere speculation?
  - First, a **theory** is much broader in scope than a hypothesis
  - Second, a theory is general enough to spin off many new, specific hypotheses that can be tested
  - And third, compared to any one hypothesis, a theory is generally supported by a much more massive body of evidence
- Those theories that become widely adopted in science (such as the theory of natural selection) explain a great diversity of observations and are supported by an accumulation of evidence
- All of the above is as quoted from Campbell & Reece (2005), p. 24

Scientific Facts

- A fact is what is witnessed upon observation
- A scientific fact is only as good as the observer, method of observation, and degree to which the environment is sufficiently controlled during the observation
- Thus, facts are very fallible and must always be considered suspect especially if they are contrary to established theory and are not repeatable under well-controlled conditions
- In other words, extraordinary claims require extraordinary proof
- In the semantics of science, a *fact* does not have explanatory or predictive power—one speaks of *hypotheses* and *theories* as ways of organizing, explaining, and extrapolating from facts
- This is why a scientist speaks of the *theory* rather than the *fact* of evolution

Scientific Law

- A law is "a statement of order or relation holding for certain phenomena that so far as is known is invariable under the given conditions" Webster
- In other words, a law, as far as we can tell, is an infallibly robust hypothesis
- In modern science it is considered reckless to call a *theory* a *law*

Scientific Reasoning

- Asking Good Questions
- Forming Hypotheses
- **Testing Hypotheses**

- A key aspect of doing science is the reasoning that goes into the designing experiments, something that I'm designating here as *scientific reasoning*
- To test hypotheses you have to understand how to go about scientific reasoning
- There are two general categories of scientific reasoning:
  - Inductive reasoning
  - Deductive reasoning
- It is the latter that is usually employed in the course of testing hypotheses and designing experiments
- *Inductive reasoning* involves the gathering of observations and hypotheses into a unifying whole

Inductive Reasoning

- "Through induction, we derive generalizations based on a larger number of existing observations." Campbell & Reece (2005) p. 20
- *Inductive reasoning* is associated with great ideas but not necessarily very good experimental design
- For example, Darwin's theory of evolution by natural selection was achieved via inductive reasoning: A great many observations were gathered and a unifying theme was discovered
- While *inductive reasoning* does not make for good hypothesis testing, the results of *inductive reasoning* can typically supply fertile ground for hypothesis making
- Another word for *inductive reasoning* is *synthesis*
- *Synthesis*, in general, is analogous to the more specific synthesis observed in chemistry laboratories. That is, *synthesis* is the build-up of a different whole from smaller parts.

Inductive Reasoning

- An example of a synthesis is the "Evolutionary Synthesis" from the middle of the twentieth century, which involved the building up, by *inductive reasoning…*

…of a theory of evolution that combined both Darwinian evolution and Mendelian genetics

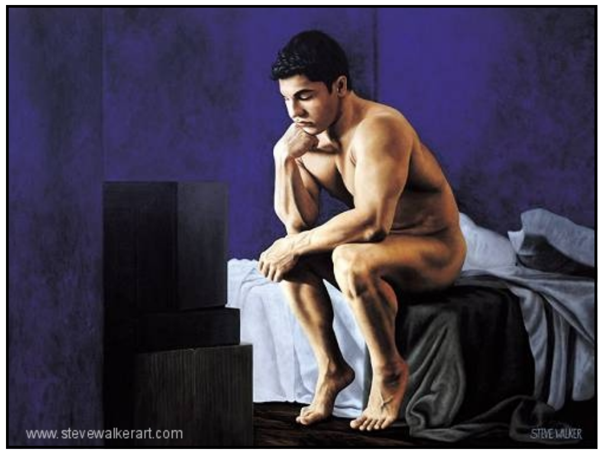
Inductive Reasoning

- "Many people associate the word *discovery* with science. Often, what they have in mind is the discovery of new facts. But accumulating facts is not really what science is about; a telephone book is a catalog of facts, but it has little to do with science. It is true that facts, in the form of observations and experimental results, are the prerequisites of science. What really advances science, however, is a new idea that collectively explains a number of observa… to be unrelat… e those that explain… menon. People like Newton, Darwin, an… ein stand out in the history of science not beca… they discovered a great many facts but because they synthesized ideas with great explanatory power." your text (older ed.)

Except, of course, Darwin *did* discover a huge number of *facts*!

Deductive Reasoning

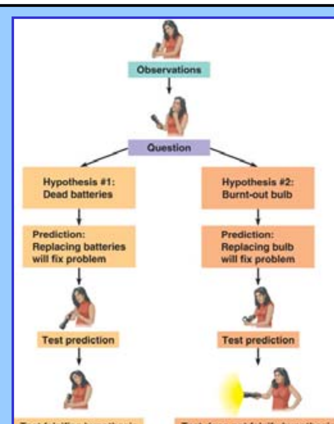
- *Deductive reasoning* is what biology is all about
- *Deductive reasoning* is an assumption of consistency
- *Deductive reasoning* is the application of generalizations to specific circumstances
- This is hardly a profound statement; It simply means the application of what we generally know to specific things that we don't yet fully understand
- More than anything else, introductory biology introduces students to a sampling of the general themes of biology
- With time you will learn to apply these themes to novel situations to *deduce* explanations for novel observations
- E.g., once you understand why lipids tend to not dissolve in water, but that carbohydrates do, you will be able to look at organic compounds that are new to you and make specific predictions as to their water solubility



Hypothetico-Deductive Thinking

- The process by which science typically progresses is employing a mechanism known as *Hypothetico-Deductive Thinking*
- This fancy phrase basically means that one understands new observations in light of previously learned or subsequently looked up general knowledge, & then phrases understanding as testable predictions
- I.e., deductive reasoning → hypothesis making
- The catch, of course, is that not all knowledge is correct, knowable, or even necessarily applicable to the new observation
- Furthermore, it isn't always obvious how to apply general knowledge to new observations
- When you have an interesting or important (and repeatable) observation that cannot be explained in detail by current scientific knowledge, what you have is the core of what I would call an *interesting scientific question*.

Hypothetico-Deductive Thinking



Doing Science as Triage

- A triage is a means of effort-wasting avoidance
- In a wartime medical unit there are three types of patients: (i) those who will survive without medical intervention, (ii) those who will not survive even with medical intervention, and (iii) those who will survive but only given medial intervention
- If you have the resources to deal with only a limited number of patients, then you concentrate first on the latter
- What is being done is prioritizing
- In science usually the first questions answered are the most easily solved or most interesting
- Less-easily solved questions or less-interesting questions are solved next (if ever)
- The least-interesting or most-difficult questions tend to be addressed last (often never)

Not Addressing *Important* Questions

- Scientific prioritizing is why questions that many consider important (Why do we exist?) are typically never considered by scientists
- In a world of interesting, solvable problems, few rational individuals commit enormous quantities of time and energy to questions that are not readily solved, no matter how interesting they may appear
- Think about your own life… When was the last time you elected to attain world peace and prosperity *before* dealing with more mundane concerns such as eating lunch or voiding your bladder?
- A *bad* scientific question typically is one in which the one's potential to answer the question, even given abundant technology and resources, is extremely limited

Skepticism

- Attitudes of skepticism derive from desires to avoid wasting one's time on questions perceived to be without significant usefulness
- This is why the burden to answer questions (demonstration of a lack of falsification of hypotheses) is placed on proponents of ideas rather than on the detractors
- Extraordinary claims—one's not consistent with an existing base of knowledge which so far has stood the test of time—typically demand extraordinary proof to be persuasive
- Such proof is found in rigorous, robust, and honest attempts at falsifying the hypothesis in an unambiguous manner

Liberal vs. Conservative

- For many hypotheses, existing technology and understanding is not sufficient to supply such proof, regardless of the efforts of proponents
- Such hypotheses are generally discarded by other scientists
- In other words, scientists are typically *skeptical* of claims that "fly in the face of reason," i.e., that are inconsistent with what is already known scientifically
- This is why scientists often come off as fairly conservative in terms of their acceptance of new ideas (a.k.a., have good B.S. meters)
- They know how much work is required to test hypotheses—that making hypotheses is far easier than proving them
- Scientists, consequently, are typically far more interested in *results of efforts to test hypotheses* than they are in the hypotheses themselves

Predicting the Future

- Sometimes, when technologies and understanding catch up with speculations, speculated hypotheses turn out to be correct
- Proposed future utility of a given hypothesis, however, is no guarantee of present usefulness
- An otherwise empty promise of future usefulness should never be accepted instead of demonstrated usefulness of a hypothesis in the present
- This is why science fiction can be very cool but nevertheless is still fiction
- The only reasonable predictions of the future is extrapolation from the past (i.e., that the future in some manner will resemble the present)
- This is *the* utility of science (and of history): efficiently and accurately defining the present and the past so as to predict the future consequences of present trends and actions

Self Correction

- "Another key feature of science is its progressive, self-correcting quality. A succession of scientists working on the same problem build on what has been learned earlier. It is also common for scientists to check on the conclusions of others by attempting to repeat observations and experiments. Among contemporary scientists working on the same question, there [is] both cooperation and competition. Scientists share information through publication, seminars, meetings, and personal communication. They also subject one another's work to careful scrutiny.“ you text (older edition)
- "In science seldom does a single test provide results that clearly support or falsify an hypothesis. In most cases the evidence serves to modify the hypothesis or the conditions of the experiment." your lab text

The Tao of Self Correction

- *Self correction* means that the testing of hypotheses is typically repeated by others so long as a hypothesis:
  - Impacts on the work of others (i.e., is important)
  - Is plausible (i.e., people are willing to believe that tests already performed could conceivable support the hypothesis)
  - Is testable by other means
  - Is contrary to other's previous understanding
- Often if a claim is too outlandish then the burden of proof will fall on the claimant, and others will simply reject the claim; This is especially the case if others don't consider the claim to be especially important or plausible:
  - Look closely at claims of cold fusion? Yes!
  - Look closely at claims of perpetual motion? No!

The End