The Scientific Method
some notes from the lecture

**Note that these notes are a combination of my notes and notes from a university of Miami class website

WHAT IS SCIENCE? It is a method used by humans to try to make sense of the world (and universe) in which they live. It is a process, meaning that it continues. Questions lead to some answers which lead to more questions etc.

Biology is the study of living organisms (from the Greek bios, meaning "life" and logos, meaning "discourse in or study of"). Within biology, there are several subdisciplines that are more narrow in focus. Here are just a few of the subdisciplines of biology...

Microbiology - the microbiologist studies microorganisms, such as bacteria
Genetics - the geneticist studies genes and inheritance
Physiology - the physiologist studies metabolism and function of organisms
Ornithology - the ornithologist studies the biology of birds
Herpetology - the herpetologist studies the biology of amphibians and reptiles
Mammalogy - the mammalogist studies the biology of mammals
Botany - the botanist studies the biology of plants
Mycology - the mycologist studies the biology of fungi
Ecology - the ecologist studies the functioning of ecosystems

...and even within these subdisciplines there are still more specific areas of study!

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Scientists all start their work by making OBSERVATIONS and noticing interesting things. first step in a very proscribed procedure we call... THE SCIENTIFIC METHOD

"The process known as the Scientific Method outlines a series of steps for answering questions, but few scientists adhere rigidly to this prescription. Science is a less structured process than most people realize. Like other intellectual activities, the best science is a process of minds that are creative, intuitive, imaginative, and social. Perhaps science is distinguished by its conviction that natural phenomena, including the processes of life, have natural causes--and by its obsession with evidence. Scientists are generally skeptics."

(from Biology by Neil A. Campbell)

So don't confuse The Scientific Method with Science, in general. Also note that if something is outside the realm of scientific testability, the wise scientists will not presume that it is not true, nor that it does not exist. Some things simply are outside the realm of Science, and cannot be addressed via the Scientific Method. Such things are considered supernatural (above nature). *This does not mean that scientists do not and cannot believe in the 'supernatural', it does mean that they don't use the scientific method to explain such phenomena.
DEDUCTIVE REASONING: From the general case to the specific (All birds have feathered wings. We know that sparrows have feathered wings. Therefore, we can deduce that "Sparrows are birds.")

INDUCTIVE REASONING: From a specific case to the general principle. (Sparrows are birds. They have wings, and can fly. Robins, flamingos, owls, and eagles are birds, have wings and can fly. From this you might induce that "ALL BIRDS CAN FLY.")

The problem with the latter is the "inductive leap": When you make the jump from many observations to saying that your observation is true in all cases, you are making a generalization that might not be correct every time.

Although generalizations can be useful, the wise scientist is always aware that there may be EXCEPTIONS to the general rule, and to the possibility that the "general rule" might eventually be found to be wrong.

Let's take the example above. You suddenly come upon an ostrich. It has wings, and all the other characteristics you'd ascribe to a bird--BUT IT CANNOT FLY! Does this mean that your general rule is always wrong? No. But it does mean that there are exceptions, and you must be ready to find them! The human mind is creative in its inductive reasoning, but it is not omniscient (all-knowing) or infallible! This is why scientists use deductive reasoning in their scientific endeavors. Such reasoning is less susceptible to this type of error.

A common theme in scientific endeavors is the use of HYPOTHETICO-DEDUCTIVE REASONING: The formulation of an hypothesis (a tentative answer to a question) and the execution of experiments from which one may deduce a general answer to the hypothesis. The steps in this process include:

1. **Observation**
2. Asking a critical question (this is the ‘larger’ question that you are interested in, but itself is too big to answer
3. Developing a **Hypothesis** (this is the more concrete answerable steps that will fill in the ‘puzzle’ which help elucidate the answer to the bigger question
4. Making a **prediction** that can be tested (what results might you expect?)
5. **Collecting data**: this can be performing experiments, making more precise observations, developing and using models. ***ideally you will have multiple approaches here, possibly testing several hypotheses -- see the sea butterfly example
6. **Analyzing** the data. What do they say? This part often involves statistics or math of some sort, graphing, looking for patterns etc.
7. Making a logical **conclusion** based on experimental results
8. Developing a **new set of questions/hypotheses** based on these conclusions, which will not be the whole picture

See the powerpoint slides with the **sea butterfly example**
Here is another example from the University of Miami website:

1. **OBSERVATION**: Flamingos eat a variety of invertebrates that they strain from the silt. Interestingly, flamingo feather color is similar to that of the shrimps they eat.

2. **CRITICAL QUESTION**: Is the color of the flamingo related to the color of the shrimp in their diet?

3. **DEVELOP HYPOTHESIS**: Flamingo color is derived from shrimp pigments.
   a. Null Hypothesis: There will be no significant difference in feather color between groups of flamingos fed different diets.
   b. Alternate Hypothesis: There will be a significant difference in feather color between groups of flamingos fed different diets.

4. **MAKE PREDICTION**: If flamingo diet is changed, its feather color will change.

5. **PERFORM EXPERIMENTS**:
   a. One group of flamingos gets a diet consisting of all items, including shrimp. *(Control – sometimes abbreviated as “con”)*
   b. Other group of flamingos gets the same amount and type of food, but without shrimp. *(Treatment – sometimes abbreviated as “trt”)*
   All other variables (habitat, light period, amount of food, etc.) are held CONSTANT in both groups.

6. **COLLECT AND ANALYZE DATA**:
   a. Possible result #1: No difference in color between trt and con groups.
   b. Possible result #2: Significant difference in color between trt and con groups.

7. **CONCLUSION**:
   a. If you get result #1, then the null hypothesis cannot be rejected.
   b. If you get result #2, the null hypothesis is rejected, and the alternative hypothesis is accepted.

The results of this study suggest further experiments. (What component of the shrimp is responsible for the color of the flamingo’s feathers? How does the flamingo metabolize nutrients in the shrimp into pink pigments?)

**Important aspects of hypotheses...**

* A **HYPOTHESIS** is a TENTATIVE EXPLANATION of a phenomenon.
* A prediction is based on past experience about the phenomenon. It’s an “educated guess” about what you expect to happen.
* Multiple hypotheses make good science. (If you have only one possible answer, you may bias your experiment and your analysis.)
* Hypotheses should be testable via experimental procedures or field studies based on the hypothetico-deductive approach.
* A hypothesis can be refuted (proven wrong, or FALSIFIED), but it CANNOT BE PROVEN CORRECT. (It is impossible to perform enough experiments to be certain that the answer will always be the same, and that the same explanation will hold true.) However, if a hypothesis is tested again and again and is never falsified, it may become elevated to the level of a THEORY.
A word about the THEORY...

A THEORY is an hypothesis that has stood the test of time. It is a well-substantiated explanation of some aspect of the natural world. It is an organized system of accepted knowledge that applies in a variety of circumstances to explain a specific set of phenomena. A theory is constantly subject to testing, modification, and refutation as new evidence and ideas emerge. Theories also have predictive capabilities that guide further investigation.


And the LAW...

A LAW is described by a sequence of events in nature that has been observed to occur without variation under the same conditions. Natural law is the basis of the experimental method in science, and is dependent upon cause and effect.

Example: The Laws of Thermodynamics

Here's a fairly new book, 2012, about science:

Ignorance: How It Drives Science by Stuart Firestein, a neuroscientist

Knowledge is a big subject, says Stuart Firestein, but ignorance is a bigger one. And it is ignorance—not knowledge—that is the true engine of science.

Most of us have a false impression of science as a surefire, deliberate, step-by-step method for finding things out and getting things done. In fact, says Firestein, more often than not, science is like looking for a black cat in a dark room, and there may not be a cat in the room. The process is more hit-or-miss than you might imagine, with much stumbling and groping after phantoms. But it is exactly this "not knowing," this puzzling over thorny questions or inexplicable data, that gets researchers into the lab early and keeps them there late, the thing that propels them, the very driving force of science. Firestein shows how scientists use ignorance to program their work, to identify what should be done, what the next steps are, and where they should concentrate their energies. And he includes a catalog of how scientists use ignorance, consciously or unconsciously—a remarkable range of approaches that includes looking for connections to other research, revisiting apparently settled questions, using small questions to get at big ones, and tackling a problem simply out of curiosity. The book concludes with four case histories—in cognitive psychology, theoretical physics, astronomy, and neuroscience—that provide a feel for the nuts and bolts of ignorance, the day-to-day battle that goes on in scientific laboratories and in scientific minds with questions that range from the quotidian to the profound.

Turning the conventional idea about science on its head, Ignorance opens a new window on the true nature of research. It is a must-read for anyone curious about science.