Scientific Method Assignment – *Hybrid* Oceanography 101

The process of "doing science" takes both logic and creativity. That statement surprises many non-scientists. While objectivity is certainly important to the scientific process (being able to distance yourself enough to get accurate information), so is ingenuity. Many people picture scientists as rigidly logical, one-dimensional beings who spout lots of jargon (okay, we don't help our own image sometimes!). In reality, though, like in business and other fields, being able to "think outside the box" is crucial in science. It's how progress occurs. Consider the scientific method as you read your textbook. All of the information in your book has been obtained by scientists following the scientific method, in a dynamic, creative process that ***builds on past knowledge*** while ***exploring new terrain***.

Science is a systematic process in which observation of the natural world leads to questions, and possible answers to such questions are proposed and tested. This process of questioning and investigation is known as the ***scientific method***. Steps in the scientific method include:

- **Observe**. The process begins with the observation of some phenomenon in the natural world. Observations must be occurrences that we can see, feel, hear, touch, smell, or measure using scientific tools (like telescopes or microscopes). Anything that cannot be directly observed in this way is outside of the realm of science.
- **Formulate a question**. This is the step that logically follows an observation that cannot be readily explained. It usually takes the form, "I wonder if….?", or "Could it be because….?"
- **Research the known facts**. Often, it is not necessary to start at square one when investigating a problem. Some questions that result from observations will have been investigated many times before, and you can use that information to answer your question, or help focus your next step in this process.
- **State a hypothesis**. A ***hypothesis*** is a tentative, *testable, falsifiable* statement relevant to answering the question you have asked about the phenomenon you observed. If a hypothesis cannot be tested, it is not scientifically useful, no matter how interesting it might seem.
- **Test the hypothesis**. This step involves the development of observations, experiments, and models to test whether or not the hypothesis correctly explains all observed cases, and could be used to correctly predict outcomes in future studies. An important feature of such testing is that it must be repeatable, not just by the original experimenter, but by others. Hypotheses are usually tested many times.
- **Accept, modify, or reject the hypothesis**. Many hypotheses are correct, and many are wrong. Proving a hypothesis wrong is not a scientific failure. Even hypotheses that are initially accepted must often later be modified, or even totally rejected, when new observations come to light. It is only after extensive testing that a hypothesis is elevated to the next level.
- A hypothesis that has undergone ***extensive, rigorous testing*** may be advanced eventually to the status of a ***theory***, a statement or relationship that is accepted by most scientists. Examples would be the theories of evolution and plate tectonics. It is a common misconception on the part of non-scientists that the word "theory" implies a highly speculative, tentative concept (i.e., "just a guess"). *On the contrary*, a hypothesis only becomes a theory after years of testing and verification. The highest status a scientific principle can achieve is a ***law***. Laws are principles explaining events in nature that have been observed to occur with unvarying consistency. Examples would be the laws of motion and thermodynamics in physics.

In practice, one of the most important skills one needs for analyzing scientific research is to be able to distinguish between the ***observations*** a scientist makes (data) versus the ***interpretations*** that he or she draws from those observations (hypotheses):

- **Good observations** are ***unbiased*** and are ***reproducible***. Scientists, however, may have several different "working hypotheses" to explain one set of observations and as new data are collected, hypotheses often change. This is absolutely alright – it's how science advances. ***"Good data are immortal"*** (i.e., once an accurate observation is made, it should never be dismissed); in contrast, hypotheses involve interpretation and can change as new data are introduced. Sometimes what's needed is to puzzle over carefully collected data and "unlearn" inaccurate or incorrect assumptions and interpretations.
- **Good hypotheses** aren't necessarily "the right answer", *and that's totally okay!* There can be multiple, equally reasonable explanations for a given set of data. Good initial hypotheses lead to new-and-improved hypotheses, perhaps more focussed or more comprehensive. A hypothesis should generate a set of predictions whereby we can formulate tests of the hypothesis.

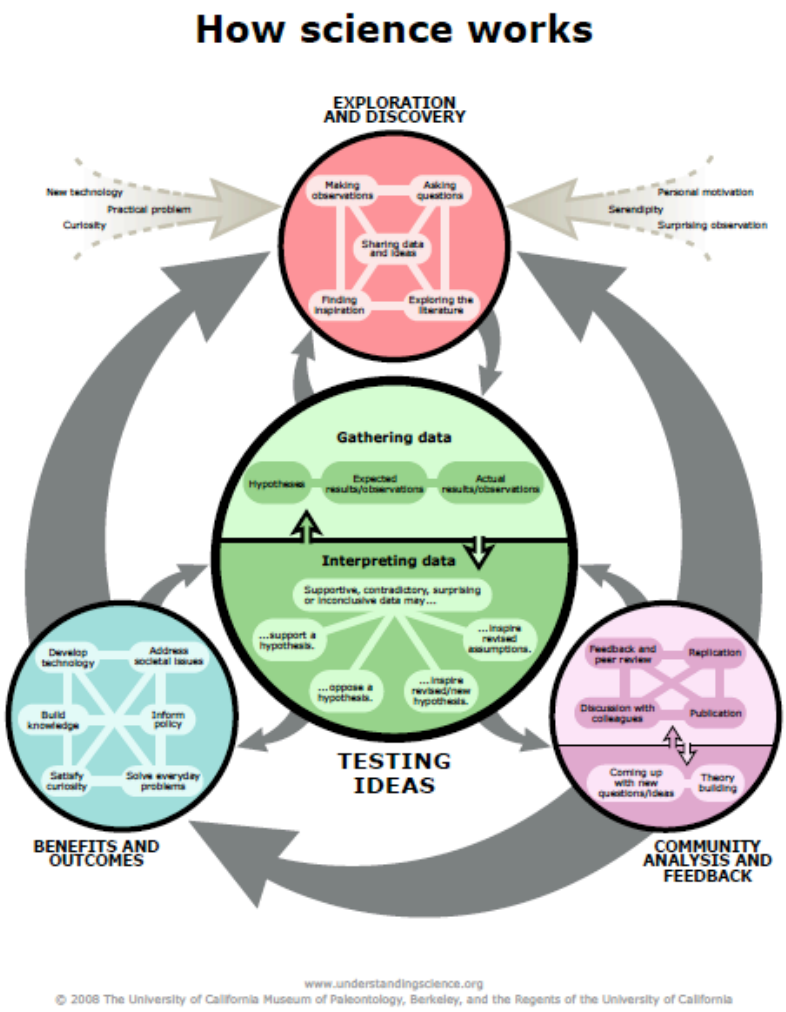
Many times the media writers – in contrast to scientific writers – do not make that distinction. For better readability, sentences in articles for the "lay public" often contain both observations *and* interpretations, and it's up to you (the reader) to figure out what are the data and what are the interpretations. Therefore, it is important for ***you*** to be able to distinguish between observations and interpretations. In this assignment, you'll do that by making observations and interpretations of your environment. Here are some xamples from a November 2, 2001 article titled "Yale and University of Chicago Researchers Discover 40-Foot Crocodile Fossil, Possibly the Largest Known So Far":

Observations:
- "The bones of a 40-foot crocodile have been discovered by researchers at Yale and at the University of Chicago in the Cretaceous rocks in Niger, Africa."
- "The largest modern crocodiles include the salt-water crocodile and Gharial, which have been recorded up to 24 feet in length."

Interpretations:
- "Our calculations in the Science paper estimate the total adult body length to be between 39 and 42 feet long, probably the largest crocodile known so far."
- "The team sectioned the bony plates in the skin called scutes and found that the animals lived for about 42 years before reaching the large adult size. They estimate that the large adults lived to at least 50 years old."

Does science ever arrive at the undisputed "truth"? Anyone who makes such a dubious claim should be considered ***misguided***. Absolute truth is not a reachable goal in science, because we can never be sure that we have acquired and fully examined all available data. And that is fine! No rational scientist will ever claim that he or she has enough data and needs no more. It is even possible that well-accepted theories and laws may be superseded by new observations that are not yet available. This should not, however, be looked upon as a weakness of science. Instead, it is a great validation of ***the strength of the scientific method***. Many of the greatest scientific advancements in history have been the result of new observations that caused a previously accepted hypothesis to be rejected.

Here is a diagram that more closely approximates the [real scientific method](#) than do most textbook representations. (Thanks, UC-Berkeley!)



Formulating Good Questions – Go Outside!

Perhaps the hardest task for any scientist is to ask a good question. As Sean Chamberlin points out in "The Remarkable Ocean World": ***"A properly posed scientific question gets to the root of the matter; the mere creation of it suggests possibilities we might never have considered; the asking of it illuminates gaps in our knowledge and exposes those parts of a problem that are most critical."***

Now it's time to put the concepts above into practice, and explore first-hand the art of scientific thinking. You can do this activity in the mountains, at the beach, in a park, in your back yard... pretty much anywhere outside "in nature". As this is a natural-science class, the questions need to be about natural-scientific subjects/observations (rather than social sciences, as interesting as that can be).

- **Go outside.** Look around you. Make careful observations. What do you see? What kinds of phenomena define the landscape? the coast? the mountains? What kinds of organisms or materials travel along or within the rivers or beach? What kinds of things can't you see that you might be curious about? Don't limit yourself or your thinking. Stretch your mind. Include the land, the sky, the sea. Observe the big picture as well as the tiny picture.
- **Write your observations in the form of questions.** *Write at least twenty (20) questions.* The reason twenty is important is because it forces you to observe and think! At about 12 or 13 questions, you run out of the obvious questions and then you really have to start looking around you. Try this little test on your questions: Ask yourself if the question would be able to be answered through experiment or further observation. If not, try to think of a way to ask the question that might make it easier to answer. *[Example: Instead of asking "Why does the ocean look blue?", you might phrase it "Does the fact that the ocean appears blue have anything to do with the sky being blue?"]*
- Pick **one** of your **questions** above, and try to form **several proper scientific hypotheses**. Remember that a proper hypothesis must be testable and falsifiable. *[Example (continued from above): "Hypothesis #1: The ocean appears blue because the light reflected off of it to our eyes comes from the blue sky." (By the way, this hypothesis is not correct, but that's okay!)]*
- For **each** of your **hypotheses** above, list **several scientific tests** beneath it. What results might be expected from each test? *[Example (continued from above): "Test #1 for Hypothesis #1: I would photograph the ocean at the same location and time every for one year. I would expect that on the cloudy days, the ocean would not appear blue."]*

1. **WRITE IT UP** – Type up your questions, hypotheses, tests, and predictions. *Be sure to number your questions!* Start with a **brief introductory paragraph** about your specific location, type of environment, date and time, and weather conditions from which your questions originated. End with a **summary paragraph** about what you learned from this exercise – Did it cause you to look at the natural world around you a little differently, and if so, then how?

2. **POST IT to the DESIGNATED DISCUSSION BOARD in Canvas** – The subject line should be **YOUR NAME – SCIENTIFIC METHOD**.