Scientific Method Lab

Physics 110

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What is "Science"

- Science, contrary to how it might seem based on what you've done in science classes, is **not** just learning (memorizing) lots of facts.
- Here is my statement of what science is:

  Science is a methodical procedure for the exploring and understanding of nature.

- A method or procedure, not a collection of facts or information.

What is “Science” (2)

- According to the American Physics Society (APS)

  Science is the systematic enterprise of gathering knowledge about the world and organizing and condensing that knowledge into testable theories.
- The APS says further that *good science depends on the willingness of scientists to (1) expose their ideas and results to independent testing by other scientists; and (2) abandon or modify accepted conclusions when confronted with more complete or reliable evidence contrary to their theory*.

Science vs. the Results of Science

- Most of this quarter, you'll be learning the results of the scientific study of astronomy.
- That will be the lots of facts and theories to memorize.
- But the goal is to, as much as possible, explain how those results were obtained; why astronomers believe some theories and not others; and have you repeat scientific experimentation if possible.
- Usually that last is not possible, but today you'll be doing some science.

Greek Science

- The ancient Greeks founded many scientific disciplines.
- The Greeks generally believed that disputes over which explanation was correct could be resolved through debate. The more logical the idea, the better its case was argued, and the more divinely inspired the idea appeared would determine which idea was correct.
- The Greeks were **not** very successful in weeding out correct ideas from incorrect ones.

Modern Science

- Modern science still requires logic and cleverness to generate explanations.
- But an incredibly successful method has been found to cull the faulty theories. This new method is to make physical measurements and use those to test which theories really match reality.
- This new “scientific method” of doing experiments to test competing hypotheses was developed by Galileo, Bacon, and others about 400 years ago.

Modern Science (2)

- The creation of this scientific method led immediately to the end of the “dark ages” and a scientific revolution.
- **Every** scientific field has adopted this scientific method and every field has been rewarded with stunning advances.
- Our world has been transformed by the scientific method: cars, electric lights, medicines, cell phones, nuclear weapons, airplanes, air-conditioners, computers, long lives, etc.

May Skip

Science and Religion

- Are these two aspects of human life incompatible?
- Why is there conflict?
- Does it have to be this way?
- Whose at fault?
- What can you do?

May Skip

The Domain of Science

- Modern science has been enormously successful in determining how the universe works.
- We now understand how gravity, genetics, electricity, volcanoes, hurricanes, the Moon, hearts, etc. work very well.
- Those that claim theories based on religious beliefs but that fail experimental tests will be ignored and discounted by the scientific establishment.

May Skip

Non-Scientific Ideas

- If an idea cannot be tested by any type of experiment, it is considered **non-scientific**.
- That means that it is outside of science, and science can make no judgment on whether it is correct or not.
- The existence of God is non-scientific, there is no possible experiment that could disprove the existence of God, any idea that is not “falsifiable” is non-scientific.

May Skip

Supernatural Theories

- “Supernatural” theories are also non-scientific.
- Such as the creationism/intelligent design alternative to Darwinian evolution.
- Creationism proposes a creator and that our world has been shaped by the whims and designs on that creator rather than shaped by natural processes.
- Supernatural theories cannot be proven or disproven so they do not belong in a science class.

May Skip

Science is Limited

- Science is very good at what it does (determining how nature works) but it is limited to that.
- Science cannot tell us what is moral behavior.
- Science cannot tell us what the purpose of life is.
- Science cannot tell us what the correct punishment for murder should be.

[Although science may be able to inform us on how or why we behave as we do, or to open new options on how to modify behaviors.]

May Skip

Domain of Religion

- Religions as moral codes, as emotional comfort, or as spiritual guidance do not conflict with science.
- Arguably they fill an enormous void in people's lives that is not and never will be met by science.

- But where religions make claims regarding how or why things occur in nature; they move into the domain of science and possible contradiction.

May Skip

Faith

- Those with faith in, say, the literal interpretation of the Bible are being non-scientific.
- Not necessarily wrong, scientific evidence that the Earth is 4.5 billion years old may simply be because God created the Earth more recently but with such evidence contained within it.
- If those with faith try to overrule those with scientific theories, there can and will be conflict.
- Of course, evolution is currently the most obvious example of such a conflict.

May Skip

Can't We All Just Get Along?

- If sciences could just make and test their theories without overstepping the line to jump to moral or ethical conclusions, they would not conflict with religions.
- If religions were to only deal with moral and spiritual issues and not make claims on physical laws or facts, they would not conflict with science.

- Maybe someday.

Models

- A **model** is an explanation of how or why something happens.
- A **hypothesis** is an untested model.
- A **theory** is a widely accepted model.
- Scientists use the word “theory” differently than it is used in everyday language. Scientific theories (like the theory of gravity or the theory of evolution) are not provisional ideas, they are ideas that have been repeatedly tested and confirmed.

Theories and “Truth”

- No theory is ever accepted as absolute “truth” in science.
- All theories are expected to be further tested no matter how many previous tests have been done.
- We’ll see examples of theories in astronomy that were widely accepted (even revered) for hundreds of years but were later shown to be incorrect.
- Models and theories, not truth, is what science produces.

The Best Theory

- I'll be teaching you about astronomical models, the best current theories explaining how things work in the universe.
- Well, sometimes I'll be teaching you simplified theories that aren't quite right; either because there is not yet any consensus among astronomers as to which hypothesis is correct or because the best theory involves mathematical or scientific knowledge beyond what we have time to learn in this class.

Scientific Method

- Models are produced and judged through the scientific method.
- Scientific models are judged in the most harsh and unforgiving way - they must predict and explain cold, hard facts.
- Depending on the scientific field, the scientific method can vary in the details.
- The following outline is common to most variations.

Scientific Method Outline

- **Problem**

  The phenomenon to be explained or the question to be answered.

Examples:

- *Why does the Sun shine?*
- *How does the dog get out of the back yard?*
- *How do we cure a patient with that type of cancer?*

Scientific Method Outline (2)

- **Hypothesis**

  A model that explains the phenomenon or answers the question

First test, the model should agree with already known facts and experiments done in the past.

In part that is why scientists have to get lots of schooling.

We generally reject any model (like the dog flies out of the backyard) if that idea has been contradicted.

Example Hypotheses

Examples:

- *Why does the Sun shine?*

  Covered in burning gasoline?
- *How does the dog get out of the back yard?*

  Crawls through that small hole under the fence?
- *How do we cure a patient with that type of cancer?*

  This drug (for whatever reason) will cure that type of cancer.

Predictions and Experiments

- Scientists (often the same scientist that came up with the hypothesis) must determine some method of experimentally testing the hypothesis.
- If there is no possible test, than the idea is not scientific.
- Experiments are designed and performed.
- Models that correctly predict the result of the experiment gain support, those that failed the test are modified or rejected.

Prediction/Experiment Examples

- *Why does the Sun shine?*

  Covered in burning gasoline?

  This hypothesis fails for multiple reasons, the Sun is not made of gasoline and oxygen which are required to burn gasoline. The temperature and age of the Sun are also inconsistent with the burning gasoline hypothesis.

Prediction/Experiment Examples

- *How does the dog get out of the back yard?*

  Crawls through that small hole under the fence?

  Block hole, see if dog no longer escapes.
- *How do we cure a patient with that type of cancer?*

  This drug will cure that type of cancer.

  Give the drug to people with that cancer and see if they get better (too simplistic, will learn how to do this experiment better later today).

Theory

- A hypothesis passing all its tests may eventually graduate to “theory” status. There is no formal or clear-cut moment when a hypothesis has reached the level of acceptance that makes it a theory.
- Again, all theories will continue to be tested and challenged by new models.

- Let’s practice applying the scientific method to a problem…

Extended Example

- **Problem:** *Does talking to plants help them grow?*

  Is that silly? Maybe. But let's consider how we would scientifically answer this question.
- **Hypothesis:** *A talked-to plant will grow more and better*.

  [A good hypothesis would also explain why talking to a plant results in better growth.]
- **Experiment:** *Plant a seed, talk to the growing plant, see how it does*. What? Not good enough?

What was wrong with that experiment?

- How do we judge whether the plant is doing well or not?
- Compare to “normal” plants? How do we know what’s normal for your house?
- Even if the plant does superbly, how do we know it was the talking and not your house and how well you cared for it.
- If it does poorly we don’t know if talking made any difference or whether it was just a poor location for the plant.

How do we judge the plant growth?

- What we need are **two** plants, one will be our "experimental" plant (that we'll talk to) and the other will be a "control" (which we won't talk to).
- This is good! Now we have something to compare.
- We can measure heights or weights of plants to get a quantitative comparison of the plants.

How can we be sure it was the talking?

- Imagine we do the experiment with two plants.
- We measure both and the experimental plant is doing better.
- *How can we be sure it was doing better because of the talking and not for some other reason?*
- That's a very important question.
- We have to make sure that the plants *are treated exactly the same in every way except for the talking!*

Things that have to be the same

- The plants must get equal sunlight (otherwise we don't know if the different growth was due to talking or the different sunlight).
- They must get equal water, have equal size pots, have the same dirt, same temperatures, and so on.
- We even need to know that the original seeds were equally good! How do we do that? Maybe we need a dozen experimental plants and a dozen controls and then we can hope the average seeds were equal.

You shouldn't take care of the plants

- If you are spending time talking to one plant and not the other, you might notice special needs (water, bugs, dead leaves) that it has but not notice such things on the control.
- Could you be really sure that the plants got perfectly equal care? Would others be convinced of your results if you were caring for both plants while spending extra time talking to one?
- Have someone else take care of the plants, someone who doesn't even know which is the experimental and which is the control plant.

Good experiments are tough to do

- Comparisons of plants should be done at some pre-determined time. Otherwise, if the talked-to plant wasn't doing better you might decide to "give it more time" - and that's not treating the plants equally.
- To ensure no bias, have someone else do the measurements of the plants, preferably someone who doesn't even know which plant is being talked to.

Drug Testing

- Although we are talking about the silly question of whether talking helps a plant grow, the issues we are facing are extremely important, they are the same issues facing scientists testing new drugs.
- Some sick patients are given the new drug while others (the controls) are not.
- Patients should be randomly selected as to whether they get the drug or not.

Avoiding any possible bias

- Doctors and nurses should **not** know who is getting the drug and who is not. Knowing can bias the results, maybe a sick patient on the real drug would be given a little more time while a control patient would not. The only way we can be **sure** that experimental and control patients are treated the same is if no one knew which was which.
- **Patients** should **not** know whether they are getting the drug or not! Why? And how do manage that?

Placebos

- Why? Because patients who think they are getting medicine tend to do better than patients who know they are not getting any medicine.
- Health is affected by emotions and the hope of a possible cure has a large psychological impact.
- How? All patients are given similar-looking pills. But the control patients are being given "placebos" which look like medicine but actually contain none.

The Placebo Effect

- In fact, a good way to make a sick person feel better is to give them something that they believe will make them better.
- While the placebo won't cure any actual diseases, the comfort of the "cure" will make a difference in how they feel (called the "placebo effect").
- Doctors still debate the ethics of prescribing placebos for patients who are not seriously ill while pretending to be prescribing a real drug.

Double Blind

- So the best drug studies are when the doctors and nurses don't know who is getting the real drug and the patients don't know either.
- That's called a "double-blind" experiment.
- In a double-blind experiment, there is no way for the results to be biased by differing treatment because no one knows who to treat differently.
- Double-blind experiments are called the "gold standard" of drug tests.

Back to the plants

- Possible differences in seeds still bothers me.
- Even averaging a dozen experimental and a dozen control plants doesn't guarantee that all things were equal.
- You're right, and that kind of thing is true about a lot of experiments.
- It's not unusual for the conclusion of an experiment to be "with 95% confidence we can say that …".

Simultaneous Effects

- When you talk and breathe, you exhale CO_2 (carbon dioxide) gas and moisture.
- Turns out that's the stuff that helps plants grow.
- The talked-to plant might do better because you are breathing on it, not because of the talking!
- *What's the solution to this? Talk without breathing? Use recorded talking? Breathe on the other plant without talking?*

Plant experiments are the easy ones

- This was supposed to be an easy experiment.
- But good experiments where you control all the variables can be quite challenging.
- And plants are far easier to deal with than sick people!

- Good science depends on good experiments.
- Hopefully you are getting a feeling for how science is done.

Be skeptical

- Because it is hard to do good science, you should distrust scientific claims from biased sources.
  - A tobacco company claims they have proven their new cigarettes don't cause cancer but won't share or explain how they proved this.
  - This pill - with a balanced diet and exercise - causes you to lose weight. Is it the pill or the diet and exercise?
  - Cell phones cause cancer. Yes, some people who use cell phones have contracted cancer. But did the phone cause cancer or might they have gotten cancer anyway. What about those people who got that cancer even though they didn't use cell phones?

Astronomy Experiments

- Astronomy is mostly an observational science, astronomers rarely get to probe or manipulate the objects of their study. Double-blind experiments are rare in astronomy.

- But some experiments, even in astronomy, can be done like we've described.
- We'll do such an experiment now.

Astrology Testing

- Astrologers claim to be able to predict (in part) what will occur to you every day based simply on where the Sun was when you were born (your "Sun-sign" or just "sign").
- Most newspapers print a daily column of astrological predictions.

- **Handouts.**

The Handouts

- Write down your name, birthday, and astrological sign on the handout.
- Before looking at the horoscopes listed (for which the signs have been removed), think about what happened to you **yesterday**.
- Relationships, money, arguments, etc.
- Now take your time, read all the horoscopes, and pick the one that best matches the day you had yesterday.
- Pick the one that seems “meant for you”.

Pick one and only one

- Fear not, you are not being graded on whether you pick your correct horoscope.
- Check your neighbors, make sure they have picked one (and only one).
- The signs that went with each horoscope are as follows…

The Test

- If astrology is correct, we might expect that 20 or more people will pick their correct horoscope.
- If astrology is wrong, then it would just be random chance, anywhere from 0 to 10 might pick their correct horoscope.

- Raise your hand if you guessed correctly.

The Result (how did I know?)

- So it appears to just be random chance.
- We have not disproven astrology.
- At best, all we've proven is that this astrologer on this day for this audience made inaccurate predictions.
- But astrology has **never** passed a scientific test.

- Nevertheless, we'll give astrology another chance.

Presidential Signs

- General personality traits are also said by astrologers to be determined by one's sign.
- It requires certain personality traits to become U.S. President (leadership, charisma, intelligence, etc.).
- So we might expect most presidents to have the same signs.

- Use the handout to count how many presidents had each astrological sign.

The Test

- If astrology is correct, we would expect many signs to have zero presidents, and a few to have a lot (8 or more).
- If astrology is wrong, we would expect it to be random, any number from 0 to 8 would be likely for each sign.

- Count presidents, answer the questions, turn in the handout, and you're done.