# What is Sound Science?...

## The Basics...

A good starting point is the Random House Dictionary, which defines science as systematic knowledge of the physical or material world gained through observation and experimentation.

Science is systematic in the sense that it is ordered, organized and methodical. Again, it can be seen that science is a process, not just a body of knowledge.

Science is based upon observation of the material world. Events must be observable and measurable. Those events which cannot be observed or measured fall outside the realm of science.

Finally, sound science is usually based upon experimentation. Experiments are designed to prove a particular hypothesis true or false. Significantly, no one experiment can be used to confirm a theory or hypothesis. Experiments must be repeatable, and actually repeated, before a new finding can become part of the body of accepted scientific knowledge.

The ability to disprove a hypothesis is what sets science apart from pseudo-sciences like astrology. A well-conducted experiment will result in a true or false condition regarding the hypothesis being tested. No such tests exist in the pseudo-sciences.

Example: The results of an astrological reading can never be proved or disproved. Astrologers will point out when their predictions are right, but not when they are wrong. More importantly, they do not (and realistically, cannot) use the knowledge gained from previous readings to make improvements or advance their prediction capabilities. In fact, scientific studies show astrological predictions to be "correct" no more than would be expected from random guessing.

Many people believe that there is something intrinsically "unnatural" about science. Nothing could be further from the truth! Physics, chemistry, biology, et al are disciplines that examine and explain nature from specific viewpoints.

## Scientific Reasoning

There are two types of thinking usually associated with the development and proof/disproof of a hypothesis:

- Inductive Reasoning, where a specific fact or set of facts is used to ascertain a general theory or hypothesis. (The swans in the park are white, therefore all swans are white.)

- Deductive Reasoning, which works the other way, starting with a general assertion and using experimentation and observation to deduce a specific fact or set of facts. (We know that swans are white. This bird is white, so it must be a swan.)

Inductive reasoning was most popular in the Nineteenth Century (A System of Logic, John Stuart Mill, 1843). It was assumed that science advanced incrementally and fact by fact, with hypotheses and theories becoming more general as specific pieces of knowledge became available. However, deductive reasoning has replaced it as the method of first choice. Such modern luminaries as Peter Medawar and Karl Popper have argued that "there is no logically rigorous procedure by which an inductive truth can proved to be so."

Both forms of reasoning appear to be essential to the ongoing process of scientific learning. It takes induction to develop grand "what if?" ideas and to generate new hypotheses. It then takes deduction to test these hypotheses. While induction helps get the ball rolling, deduction is the true workhorse of the scientific world, forming the basis for what is known as the Scientific Method.

## Inductive Reasoning

Inductive reasoning is based upon arguments which do not contain categorical support for a conclusion. Rather, they confer only probability on the conclusion, which means that it is possible for premises to be true and the conclusion false.

Example: The premise that "Most people like ice cream" is true, as is the premise that "Mary is a person". The conclusion that follows, "Mary likes ice cream" is logically correct, but may not be true. The reason for this is that while we have stated that most people like ice cream, Mary may not be one of them.

Because inductive reasoning is based upon probabilities, conclusions are considered to be cogent, rather than true. This is because the probability exists that the two accepted premises may not truly lead to the acceptable conclusion.

When developing or listening to an argument, words such as "Most" or "Some" are a tipoff that inductive reasoning is being applied. There are 2 significant ways in which the conclusion can be wrong:

1. It may fall outside of the probability range of the premises, as in the example above.

2. The premise itself may be inaccurate -- Words such as "many" and "some" could be nothing more than editorializing or wishful thinking by the presenter.

   If possible, try to turn "Most" into a specific amount, e.g., "80%." Doing so will provide a more accurate framework in which to assess the argument, while not being able to do so is cause for skepticism.

## Deductive Reasoning

Unlike induction, deductive arguments provide absolute support for a conclusion. Deductive reasoning makes the strong assertion that the conclusion must follow the premises out of strict necessity. Denying the conclusion means that at least one of the premises is self-contradictory and thus not true.

Example: From the statements "All creatures need water to live" and "I am a creature" follows the conclusion that "I need water to live" Note that the critical difference between this line of reasoning and the previous inductive example is the word "All" rather than the word "Most".

Because deductive conclusions must be true if the premises are true, a logically correct deductive argument is termed valid. (Note also that deductive reasoning takes arguments from very general to very specific outcomes.)

The key to the credibility of a deductive conclusion lies in the premises. Since the conclusion must follow from the premises, the only way for a deductive argument to be considered invalid is if one of the premises is proven false. Make sure that the word "All" truly applies to the premise in which it is used. Otherwise, the argument will fall apart.

## Scientific Method

The Scientific Method is a standard for conducting credible science. It is intended to be an unbiased process by which neutral and objective scientific inquiry can occur.

The cornerstones of the Method are the concepts of reliability and validity. Results are considered reliable only if they can be replicated by third parties. Results are deemed valid only if they meet the strict logical criteria that has been established for deductive thinking. Both reliability and validity require the Scientific Method to be an open process subject to continual appraisal, scrutiny, criticism and revision.

Contrary to popular belief, there is no specific step by step procedure that can be called the Official Way. However, the Scientific Method always encompasses certain steps:

1. Identify a Specific Problem
   In this case, a problem is not necessarily something negative, but rather a situation where the result or effect is understood but the cause needs to be identified.

2. Develop a Hypothesis
   A hypothesis is a tentative, educated explanation of the facts. Development of a hypothesis requires inductive reasoning, whereby a few specific facts lead to the creation of a broad explanation.

3. Test the Hypothesis
   An experiment which tests the hypothesis is designed and conducted. Experimentation is a science unto itself, as a good design must account for and control all of the variables that might affect the results. A good experiment ensures that only the variable in question can cause or create the hypothetical outcome.

4. Draw Conclusions
   Conclusions generally are of three varieties: the hypothesis is true, false or needs to be modified to better reflect the newly discovered facts.

5. Re-Test the Hypothesis
   One test does not a new theory make. Findings must be re-tested and re-analyzed many times by independent third parties to verify and confirm the results. Studies are often published, in an attempt to both report results and alert others to the need to scrutinize and validate the data.

   Because nothing can ever be proven with complete and total confidence, many scientists will tell you that a theory is never right -- it just hasn't been proven to be wrong. (We're back to Einstein again!)

Example: You wish to determine why the wall lamp in your living room doesn't work. Based on prior knowledge and observation regarding similar situations, you formulate the hypothesis that the bulb is faulty.

You then devise an experiment to confirm the hypothesis: You will replace the bulb that doesn't work with another one that has worked very recently, and is assumed to still work. If the new one works, your hypothesis is confirmed (and hopefully your problem is solved).

First, you minimize the probability that the problem is due to anything other than a faulty bulb by doing the following:

- Checking that the cord from the lamp to the outlet is intact.
- Checking the fuse box to ensure that there is power to the lamp circuit.
- Testing the circuit to ensure that it provides consistent current at the proper voltage and amperage.
- Confirming that there are no wall switches which can be used to turn the lamp off & on.
- If there is a switch, confirming that it is on.

Now for the experiment: You put a different bulb that has been proven to work into the lamp. If you turn the lamp on and it lights, your initial bulb must in fact be faulty. Your hypothesis has been confirmed.

On the other hand, if the new bulb doesn't light, you still don't know whether the problem is that the old bulb is faulty, the new bulb is also faulty, the lamp is broken, or all three! You must go back and reformulate the experiment, and possibly the hypothesis.

This example shows the precision with which experiments must be developed. As importantly, it illustrates the fact that the scientific method is a process, the results of which can easily lead to more experiments as well as new or reformulated hypotheses. Note: Even though the experiment failed to confirm the hypothesis, significant learning did occur.

## Experimental Design

A well-designed experiment has a well-defined objective, is precise, can estimate error and can distinguish the strength and presence of various effects.

## Test vs. Control

One of the most important aspects of experimental design is the test versus control situation, in which two almost identical versions of the experiment are run. The objective is to eliminate, or hold in check, those variables which could "confound" the ability to draw confirmatory conclusions. Theoretically, the only difference that should exist between the two groups is that the control version does not include the variable in question, or includes a different level or concentration of the variable than does the test condition.

Example: To test whether or not fertilizer can make pea plants grow more rapidly, you would start with a number of identically sized and aged pea seeds. All would be placed into equivalent pots at a similar depth in similar soil. All would receive the same amount of water and exposure to light.

Half the pots would form the test, the other half, the control. The test group would receive fertilizer, the control would not. After a few weeks, plant growth would be measured and the mean growth of the two groups would be compared.

Once the presence of fertilizer is established as a growth agent, the test sample could be used as a control group: Additional studies could compare differing levels and types of fertilizer to determine optimal growing conditions for pea plants.

The use of well-matched test and control groups is thus critical to the pursuit of sound science. In the case of the peas, a comparison of merely one test versus one control plant could seriously affect the results and therefore the conclusions of the study: What if one of the two plants had died of a fungus or bug infestation, or been genetically defective in some way? Results would thus not be attributable, either solely or in part, to the presence or absence of fertilizer.

Using test and control groups of specimens significantly increases the probability of developing statistically reliable data. Group results, in the form of averages, can be used to ensure that differences which occurred between the two groups is greater than any differences that occurred within them. Also, using multiple specimens allows the experimenter to throw out a deviant specimen without needing to abort the entire experimental procedure.

## Experimental Bias

It is also important to understand that observations and analyses made by those running an experiment might be affected by the outcomes they expect; while the actions of those participating in a study could be affected if they pick up on these cues, or if they have their own expectations regarding the results.

A standard technique for reducing this type of bias is the double-blind procedure. Neither the technicians nor the participants are made aware of the type of group (test or control) in which they are involved, hence they are both "blind" concerning the initial situation or the expected results.

## Causality

Obviously, a key reason to observe and experiment is to try and gain an understanding of both the presence and strength of cause and effect-related variables. Yet even with good scientific methods, the results may turn out to be far from accurate:

Hypothetical Example: A researcher examines different environments to ascertain the cause of malaria. From an analysis of out-breaks it is concluded that malaria is caused by an airborne disease that only survives in warm, wet climates. People living in the tropics are advised to wear masks, and a massive education program is launched to make them aware of the need to do so.

In reality, malaria is caused by bites from certain tropical mosquitoes that carry the disease. By not studying the problem more closely, huge amounts of time and money would have been expended to eradicate the disease, without producing any appreciable reduction in its occurrence.

Good research attempts to develop and discuss statistical measures of cause and effect. Known as causal analysis, these methods include measures of correlation, regression, variance and covariance.

## Peer Review

Good research is peer reviewed. A panel of disinterested experts will scrutinize and analyze a study to a.) determine if the experimental design was sound, and b.) ensure that the conclusions are technically correct and consistent with the findings. Beware of research that has not been peer reviewed. Also, be suspicious of review panels "stacked" with people who would normally be sympathetic to the views of those paying for or conducting the research.

### Transparency

Good research hides nothing. Everything about the study should be "transparent", i.e., readily available for review. This includes all of the raw data developed during the study -- even the data points that were thrown out. Having transparency ensures that the study is completely reproducible, allowing others the opportunity to reproduce the results. Studies where information has been lost or is unavailable should be viewed with extreme caution.

## Junk Science...

The term "junk science" is used to describe poorly designed or conducted research. In some cases, the motivation is purely benign, with researchers starting with the sincerest intentions. Nevertheless, poor methodology results in data and conclusions that are invalid, unreliable and unconfirmable.

In other cases, the intent of junk science is more malicious, purposely abusing scientific methods in order to support a personally or politically favorable agenda or ideology. This type of deception knows no political bounds and is conducted for and by academia, special interest groups, government and industry.

Most people interested and dedicated to providing the public with factual information -- policy makers, journalists and teachers, to name a few -- are not readily equipped to see through the distortions. It is thus very important to find out why a study has been conducted and reported, who paid for it, and what they have to gain from the results.

### A Prime Target

An area of study that is particularly prone to junk science is epidemiology, the medical science interested in the factors controlling the presence or absence of a disease or pathogen. Epidemiology tends to be observational, rather than experimental, because ethics demands that we observe, rather than experiment, on people. Studies are conducted on very large populations and attempt to draw statistically valid associations between certain diseases or conditions and specific risk factors.

Epidemiological research can be the stuff of front-page headlines, because it discusses risks related to life and death. Conclusions can be emotionally charged, generating high levels of personal fear and expectations about immediate action. Taking a calm and distanced approach to analyzing epidemiological results is therefore crucial, since conclusions can have enormous political and economic impact.

One of the most important aspects of epidemiology is the idea that the dose makes the poison. This means that the effects of a substance are determined by the quantity that is present and/or the length of time it is administered.

Example: An extremely small amount of aspirin is useless from a therapeutic standpoint. A moderate dose is an effective pain killer. A very large dose can cause severe complications and even death. From a time perspective, one aspirin taken today will do nothing, but one aspirin taken every day may help reduce the risk of heart attacks.

Watch out for stories that trumpet a particular chemical or environmental factor as either beneficial or problematic without stating the quantity and amount of time needed to create the result in question:

- Special Interest Group A might say that "taken in large enough doses, food could kill you."

  True, but virtually no one consumers enough food to cause death from overeating.

- Or, Company B might argue that its product "kills 80% more germs" than a similar product from Company C.

  This too might be true, but will be of little value if both products reduce germs to levels that are well below accepted standards for risk.

## Summary...

The use and understanding of scientific principles is a critical part of the informed decision making process. Since it is fairly easy to be fooled by questionable science, no evidence, report or conclusion should be taken at face value. Learn all you can prior to making a decision.

Here is a list of questions to ask when shown the results of a "scientific" study:

## Sound Science Crib Sheet

1. What institution conducted the research? Research should be conducted by institutions, not by individuals currently or formerly associated with them. Also, try and establish that the institutions are respected and credible, with a history of doing sound scientific research.

2. For whom was the research conducted? Much of the time, reputable institutes are given research grants by government, environmental and industry groups. These groups are hoping that studies will either prove or disprove a particular point of view.

   For example, the Tobacco Institute may fund a lung cancer study to be performed by Johns Hopkins University. There is nothing wrong with this situation, as long as the funder exercises no control over the study's design, execution, results or conclusions.

3. When did the study occur? Make sure that results are recent. Otherwise, it's possible that the conclusions have been superceded by more recent studies.

4. What are the credentials of the people conducting the research? Medical research should include PhDs in the specific discipline being studied. Watch out for studies with "experts" whose credentials seem to be in fields that are not directly related to the research in question.

5. Were results published in a respected scientific or medical journal that routinely conducts peer reviews? Look for names like Nature, Science, The Journal of the American Medical Association or The Lancet.

6. Is the sample size large enough to be projectable? Studies of small samples are of dubious value.

7. Was the sample selected properly? Try to make sure that bias is reduced through the use of properly matched test and control groups. Check the reports for sections discussing methodology and any potential problems relating to it.

8. Did the study contain other methods to eliminate bias and confounding variables? Good studies go to great lengths to minimize the potential for error. They also go to great lengths to explain both what bias or errors may still exist.

9. Are results consistent with the generally accepted body of research on the subject? Don't draw conclusions from single studies or ones that contradict the preponderance of available evidence.

10. Are there other possible reasons for the relationship being discussed? This is a far bigger possibility than you might think! It is also another reason to not rely solely on the results of a single study.

## References...


1. American Association for the Advancement of Science

2. The Junk Science Home Page, a funny and enlightening look at less-than-sound science

3. National Academy Press Reading Room, a terrific on-line science resources

4. The Dose Makes the Poison, M. Alice Ottoboni, Van Nostrand Reinhold, 1991).

5. Late Night Thoughts on Listening to Mahler's Ninth Symphony, Lewis Thomas (Penguin Books, 1980).

6. The Limits of Science, Peter Medawar (Oxford University Press, 1984). Note: This book is out of print.

7. The Logic of Scientific Discovery, Karl R. Popper (Routledge, 1980).

8. Science as Social Knowledge: Values and Objectivity in Scientific Inquiry, Helen Longino (Princeton University Press, 1990)

9. Science Matters: Achieving Scientific Literacy, Robert M. Hazen and James Trefill (Anchor, 1991).

10. The Strange Case of the Spotted Mice: And Other Classic Essays on Science, Stephen Jay Gould and Peter Medawar (Oxford University Press, 1996).

11. The Structure of Science, Ernest Nagel (Hackett, 1996).

12. Tainted Truth, Cynthia Crossen (Simon & Schuster, 1996).

13. What Causes Cancer? D. Trichopoulos, F.P. Li, D.J. Hunter, Scientific American (September 1996).