The Hierarchy of Scientific Knowledge

1. Speculation

A vaguely formed idea usually based upon limited observational material.

2. Hypothesis

A tentative explanation of a phenomenon or group of observations in terms of causal mechanisms. Scientific hypotheses are often expressed as mathematical relations between observable quantities. A valid scientific hypothesis must have predictive value which renders it falsifiable.

3. Theory

A theory is basically an hypothesis which not only succeeds in explaining some phenomena but all of whose predictions been adequately confirmed (when possible) by means of additional observations or experiments. A theory is a successful working hypothesis with remaining predictive power.

4. Law

A scientific theory with broad predictive power ('usefulness") and an extensive history of successful testing might be elevated to the status of of a Scientific Law, particularly if it forms the basis for explaining a wide range of phenomena.

"But It's Only a Theory ....."

Implication: There are no particularly strong reasons for believing its statements are true, its explanations valid, or its predictions to be taken seriously.

Circumstances: Usually from a source who disagrees with the implications of the theory on social, political, theological, or "inertial" grounds.

This particular criticism is almost never raised against a theory unless it is perceived as a threat to deeply held beliefs, intuitions, or behavioral patterns. An alternative scientific theory is almost never offered. Theories dealing with human origins, evolution, or behavior are particularly subject to this comment.

Response: A Theory is usually an hypothesis of fairly broad application which has successfully passed extensive observational or experimental tests. Its assertions or predictions are more likely to be "true" than those of mere speculations or less tested alternative hypotheses.

Is It A Science?

Science, as a discipline, is defined by its methodology. Not all human activities which claim to be a "science" or "scientific" meet the requirements of that definition.

To be considered a Science, all of the following must be true

Its statements and assertions are ultimately based upon observations of the physical world.

Its hypotheses are logically consistent structures which offer causal explanations for those observations.

Its theories have both explanatory and predictive power and are consistent with other observations of the physical world.

Its hypotheses and theories are required to be falsifiable. (and the discipline willing to subject these ideas to testing.)

Science, Bad Science, & Pseudoscience

Good Science

A well-defined statement of the problem or question
Careful application of the Scientific Method

- Care in Observations and/or Careful Experimental Design
- Quantification of observations (and appreciation of errors).
- Specification of causal relations in terms of known processes
- Consistency (or non-contradiction) with other types of observations.
- Predictions (the more the better) following from the hypothesis
- Rigorous Observational and/or Experimental Tests

Bad Science

An ill-defined formulation of the problem
Careless application of the Scientific Method

- Poor data selection
- Inadequate or flawed data.
- Errors of interpretation (e.g., over interpretation) of the data

Examples: Cold Fusion, Polywater,

Fraudulent & Dishonest Science

Motivations: Notoriety, Fortune, Hoaxes, ...
Examples: Massive Elements, Medical Research, Piltdown Man & Bigfoot, ...

Science, Bad Science, & Pseudoscience

The Pseudosciences

Historical Origins

Astrology and Astronomy
Alchemy and Chemistry
Palmistry, Phrenology, Homeopathy, ...

The pseudosciences are largely based upon hypotheses which had poor observational and/or causal bases and which have been repeatedly falsified. Their persistence is of some sociological interest.

Checks and Balances in Science

- **Training and "licensing" of the practitioners of science.**
- **Peer review (Reviewers and referees)**
- **Replication of observations and experiments. (Publication of methods)**
- **Penalties**

Reprise: The Scientific Method

Application of the Scientific Method involves four steps:

1. **Observations**
2. **Formulation of Hypotheses**
3. **Predictions**
4. **Testing**

An iterative process involving continued testing, possible modification of the hypotheses, and additional observational or experimental investigation. The process terminates only if the hypothesis is falsified.