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WHAT MAKES FOR A GOOD SCIENTIFIC THEORY?

The standard "scientific method" is roughly: identify a question, formulate a hypothesis, design an experiment, run the experiment, and confirm/disconfirm the hypothesis based on the result.

This is perhaps how science operates in many cases. But in other cases, it conflates two different parts of scientific procedure: *discovery* versus *justification*.

> **Discovery** can be rather chaotic! We all know stories where an important discovery occurred by accident (x-rays, penicillin, etc.).
>
> **Justification** is needed to verify that we have not simply made a mistake. This is often where experiments are performed, in order to *double-check* our theory of *X* rather than make an initial discovery.

So often, assessing a scientific theory is not simply a matter of asking whether the scientific method was followed. But how should we assess a scientific theory? There's been lots of discussion on this; below is my attempt to summarize the insights of those discussions.

Assessing a Scientific Theory

First off, a **scientific theory of *X*** has (roughly) three parts:

(A) Background Theory—statements taken for granted when making observations, predictions, and explanations about *X*. (E.g., chemistry often takes for granted some physics, plus the reliability of certain tools and methods, etc.)
(B) Observation Record—statements of observations about *X*.
(C) One or more Predictions/Explanations about *X*—inductive and abductive conclusions meant to be supported by (A) and (B).[1]

A scientific theory of *X* is **a good theory *to the degree* that**:[2]

(1) (A) is **widely accepted** in the field.
(2) (B) is based on **well-designed experiments** and **verifiable observations**.
(3) Assuming (A) and (B): The predictions/explanations in (C) are **more likely than any competitor** predictions/explanations.
(4) The theory is **internally coherent**, **adequately comprehensive** (it includes all relevant data about *X*), and **exactly formulated** (e.g., mathematical precision is used when possible).
(5) The theory exhibits **pragmatic virtues** (see below).

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[1] To avoid complications, I will also assume that a "scientific theory" is *deductively closed*: It is assumed to include all the deductive consequences of (A), (B), and (C).
[2] Each of (1)-(5) are not equally important to the worth of a theory. E.g., well-designed experiments are more important than fruitfulness (a pragmatic virtue). Yet it is unclear how much weight each of (1)-(5) should have.

Judging (1)-(5) is aided by **<u>further guidelines</u>**:

Re: (2). The gold standard is a ***randomized controlled trial*** (RCT) with an ***appropriate sample size***, subjected to much ***peer review***. Where applicable (e.g., in medicine), such a trial should also be ***double blind*** and ***placebo controlled*** (see Forseman et al., ch. 6).

Moreover, data should be ***unambiguous*** (no fuzzy pictures of bigfoot, etc.). Experimental procedures and data-collection should be ***well documented***. These ensure that the experiments are ***replicable***, both in execution and in results.

Finally, ***limitations should be recognized*,** including the in-principle limits on any retrospective studies, case studies and anecdotal evidence, in vitro studies, or non-human animal studies (see Forseman et al., ch. 9). Also, data points from faulty data collection or other ***flawed data should be eliminated***. Insofar as possible, ***anomalies should be accounted for***.

Re: (3). Correlations that justify predictions/explanations should be ***statistically significant*** (p-value ≤ .05).[3] Causal statements can be judged against the ***Bradford Hill criteria*** (see separate handout).

Re: (5). The theory should be ***falsifiable*** and should exhibit, as much as possible, the following virtues (cf. Forseman et al, ch. 9):[4]

a. ***Predictive power***: The theory reliably predicts phenomena concerning *X*.
b. ***Explanatory power***: The theory comprehensively explains phenomena concerning *X*.
c. ***Coherence with other accepted theories***: The theory does not contradict other accepted theories, and some of its aspects are predicted/explained in light of these other theories (or vice-versa).
d. ***Simplicity***: The theory does not posit more entities than necessary to support its predictions/explanations. The theory is not needlessly complicated conceptually or ideologically.
e. ***Fruitfulness***: Where applicable, the theory generates new, compelling hypotheses for investigation.

Sometimes there must be "trade offs" between these virtues. For example, an increase in explanatory power often requires a decrease in simplicity. But the trade may be worthwhile, depending on our goals and interests.

<u>Note well</u>: An unjustified theory according to these criteria is not necessarily *false*. But it is a theory which is lacking in scientific justification.

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[3] A low p-value indicates a high probability that an effect is not due simply to random chance. Standardly, a p-value of less than .05 is necessary for ruling out random chance. But it is not sufficient. The so-called "replication crisis" is partly due to assuming otherwise. On the insufficiency of a low p-value, I highly recommend the following interactive website: https://projects.fivethirtyeight.com/p-hacking/

[4] Foresman et al. include "replicability" on their list of virtues, but I included it earlier as a virtue of an experiment rather than a theory. Also, in a – e I am only concerned with the "pragmatic" virtues of a theory.

<u>Signs of a Hack</u>

You can identify unjustified theories according to the above guidelines, but **advocates** of unjustified theories can often be identified by the following vices:

1. They advocate their views **not in scientific journals** but rather through the media and popular culture.
2. They **resist independent testing** of their views.
3. They are prone to **fallacies**, especially the appeal to authority and/or tradition, and do not adhere to the pragmatic virtues:
    i. Their authorities are often believed to have "special" abilities for knowing the truth; others must simply defer to their judgment.
    ii. Unfalsifiable or overly complex conspiracy theories are offered to explain why their views aren't more widely accepted.
4. They exhibit **biases**, especially apophenia, the overconfidence effect, and confirmation bias (cherry-picking favorable evidence, ignoring unfavorable evidence).
5. They emphasize **low-quality evidence** among their favorable evidence, e.g., ambiguous and anecdotal evidence, poorly designed and/or non-repeatable experiments.

A way to sum up 2 – 5 is: A hack is **dogmatic**.

Unfortunately, some legitimate scientists can exhibit dogmatism as well... So the above signs are not infallible indicators of a hack, but they should raise suspicion. (Though again, an unjustified theory is not necessarily false, even if peddled by a dogmatist.)