The scientific method

An early model of the scientific method was inductivism: repeated observations of associated phenomena lead to general laws. That this attractively simple notion has no logical basis is easily shown by considering the story of the turkey which observed that its feed arrived after the lights came on for 364 consecutive days. Its conclusion that the illumination caused the appearance of food was proven wrong on Christmas eve.

An improvement on inductivism focused on testing predictions. Predictions can be derived from general laws and then put to the test. Positivists argued that by confirming the truth of the predictions (verification), one proves the truth of the theory. Alas, this is logically fallacious because any particular observation is compatible with more than one theory, as illustrated in Box 2.

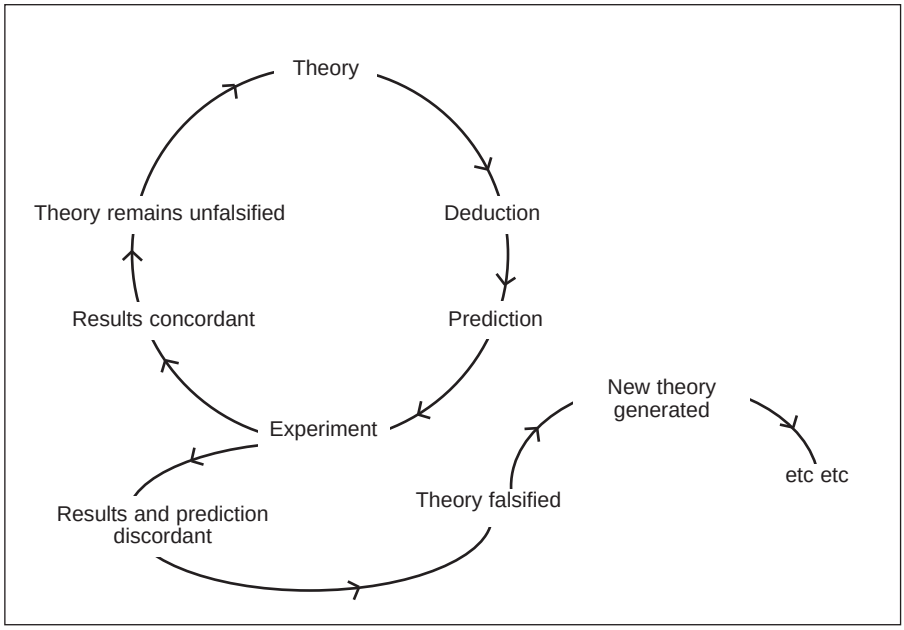
It follows that verification of a theory is not possible. However, falsification is possible. Finding a viral cause for an infection, for example, falsifies both of the theories in the example in Box 2. The concept of falsification is central to the hypotheticodeductive model of science (Figure 1). This states that scientific knowledge grows through a succession of theories, new theories supplanting older ones which are rejected when their predictions are refuted by experimental evidence, a process which has been called conjecture and refutation.[13] A distinguishing feature of science is that its hypotheses permit predictions that can be subjected to falsification through experiment.

This model accepts that there can never be certainty as to the truth of a theory; the best you can say about a theory is that it has not been falsified — yet — and that it has more descriptive power than the theory it supplanted. An important aspect of the hypotheticodeductive model is an understanding of the relationship between new and old theories: even falsified theories may have descriptive power and new theories may explain the limitations of the old. For example, we now know of many infections in which Koch's postulates do not apply (Box 3). However, modern theories of infection allow us to understand why Koch's postulates were so successful in explaining some infections.

Box 2. A hypothesis cannot be verified by evidence.

Let us start with the hypothesis:	'All infections are caused by bacteria'
From this we deduce:	'Therefore, abscesses are caused by bacteria'
From which we can devise an experiment:	We should be able to culture bacteria from the pus
The result of our experiment is:	*Staph. aureus* grown on agar plates
Does this prove the hypothesis?	No, because the result of the experiment is also compatible with the theory that all infections are caused by bacteria *or* fungi

Figure 1. The hypotheticodeductive model of science.



References continued

13. Popper K. Science: conjectures and refutations. In: *Conjectures and refutations. The growth of scientific knowledge.* 4th edn. London: Routledge and Keegan Paul, 1972.
14. Bricmont J, Sokal A. Defense of a modest scientific realism. In: *World and Knowledge.* Bielefeld-ZiF conference on 'Welt und Wissen — Monde et Savoir — World and Knowledge', Bielefeld, 18-20 June 2001.
15. Giacomini M, Cook D. Users' guides to the medical literature: XXIII. Qualitative research in health care A. Are the results of the study valid? Evidence-Based Medicine Working Group. *JAMA* 2000; **284(3):** 357-62.
16. Haig B. *Grounded theory as scientific method*. Philosophy of Education Society, 1995. http://www.ed.uiuc.edu/EPS/PES-Yearbook/95_docs/haig.html (accessed 31 Mar 2004).
17. Kumar S, Gantley M. Tensions between policy makers and general practitioners in implementing new genetics: grounded theory interview study. *BMJ* 1999; **319(7222):** 1410-1413.
18. Denzin N, Lincoln Y, eds. *Handbook of Qualitative Research.* Thousand Oaks: Sage; 2000.

Four criteria must be satisfied for an organism to be implicated in a disease:
- The bacterium must be present in every case of the disease.
- The bacterium must be isolated from the diseased host and grown in pure culture.
- The specific disease must be reproduced when a pure culture of the bacterium is inoculated into a healthy susceptible host.
- The bacterium must be recoverable from the experimentally infected host.

Examples of infections that do not satisfy Koch's postulates:
- The pneumococcus and meningococcus live as commensals in the throats of many healthy people (5%).
- Chronic infections with *Helicobacter pylori* causes overt disease only in a minority of individuals.

Box 3. Koch's postulates.

This model jars with many peoples' perception of normal scientific activity. A scientist, they would say, sets out to gather data that proves rather than disproves his or her theory. This social behaviour of individuals is not discordant with the hypotheticodeductive model because all individuals, whether scientists, lawyers or politicians, will want evidence that backs up their prior beliefs. What matters is what happens to the theory when the evidence is found rather than what motivated its collection.

The hypotheticodeductive model is very different to positivism. If any '-ism' is to be applied to science it should be realism: the belief that science aims to discover how things really are and while it can never fully reach that goal, science constantly progresses towards it.[14]

Realism in social science as applied to medicine

Some qualitative researchers work within a realist perspective. Studies using grounded theory methodology are now commonplace in medical journals. Grounded theory has robust techniques for capturing the range of human experience and belief. However, even realist qualitative researchers misunderstand the scientific method, demonstrated by some of their claims for the superiority of qualitative over quantitative research. One example is the proposition that qualitative research generates theories while quantitative research merely tests them, as seen in the *JAMA* Users' Guide to the Medical Literature (Box 4):

> '*Quantitative studies (such as epidemiologic investigations and clinical trials) aim to test well-specified hypotheses concerning some predetermined variables … Qualitative research questions tend not to ask "whether" or "how much" but rather to explore "what," "how," and "why." Qualitative studies may pursue a variety of theory-generating aims, including to faithfully explore and describe social phenomena (including surveying diverse perspectives or giving voice to those not usually heard), to identify potentially important variables or concepts, to recognise patterns and relationships, and to generate coherent theories and hypotheses.*'[15]

This contrast is false. Biomedical research is about developing theory since it is an indispensable part of the hypotheticodeductive model.

Some proponents of grounded theory argue that their theories arise from the data, through an iterative process that is active throughout the research program. A moment's reflection should suffice to recognise the inductivist method being resurrected. When confronted with this criticism, many grounded theory researchers retreat from an inductivist position.[16]

Despite claims that qualitative research does not ask quantitative questions, many qualitative research papers in medical journals do precisely that. A study of the opinions of policy makers and GPs on implementing new genetics provides one example[17]:

> '*Our data suggest that* many *general practitioners do not believe that genetic testing for susceptibility to common disorders is likely to become a routine part of their practice in the near future. We have sought the opinions of a range of general practitioners, and our results highlight tensions between how policy makers and general practitioners view the role of general practitioners in genetics.*' [Emphasis added.]

In this statement, the authors are generalising from their sample to all GPs and are making quantitative comparisons between GPs and policy makers. They are doing this without the safeguards that are expected in quantitative research, such as adequate sample size. Some would retort that qualitative research should not be criticised for failing to meet the standards of, say a clinical trial, when so many trials fail to do so. This misunderstands the point being made. Poorly designed or conducted trials constitute bad science; qualitative studies, however well designed and conducted, cannot have the same status as science because they do not employ the methods of science, methods designed to improve validity.

Qualitative research poses an alternative to validity in the form of triangulation.[17] If two qualitative studies using different methodologies arrive at similar conclusions, they are said to provide corroborating evidence. However, if they arrive at different conclusions, they are not said to refute the other. Therefore, triangulation can never provide the same falsifiability test as the hypotheticodeductive model. This statement does not imply that qualitative research has no value or meaning. Unlike logical positivism, support for the hypotheticodeductive model does not imply that only science has meaning. The hypotheticodeductive model, as Popper frequently stated, demarcates science from other disciplines over the question of method not of meaning.[13]

Conclusions

Many contemporary criticisms of science and medical science are based on false characterisations of the scientific method and on imprecise usage of the terms linearity, reductionism, and positivism. The alternatives can sometimes fall into the traps the scientific method was developed to avoid. The hypotheticodeductive model does not deny the value or meaning of other disciplines, but it does clearly demarcate what constitutes the scientific method from others. It doing so, it provides both a coherent description of the growth of scientific knowledge and a prescription for the conduct of good science.

Kevork Hopayian

Box 4. Scientific realism: a noble tradition.

The idea that we can never know the truth is a logical consequence of the hypetheticodeductive model but it had been proposed by the ancient Greek philosopher, Xenophanes, 400–500 years BCE.[13]

'Through seeking we may learn and know things better.
But as for certain truth, no man hath known it,
…The final truth, he would himself not know it;
For all is but a woven web of guesses.'