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Sophisticated Falsificationism, Novel Predictions and the Growth of Science

1. Relative rather than absolute degrees of falsifiability

In the previous chapter, some conditions that an hypothesis should satisfy in order to be worthy of a scientist's consideration were mentioned. An hypothesis should be falsifiable, the more falsifiable the better, and yet should not be falsified. More sophisticated falsificationists realize that those conditions alone are insufficient. A further condition is connected with the need for science to progress. An hypothesis should be more falsifiable than the one for which it is offered as a replacement.

The sophisticated falsificationist account of science, with its emphasis on the growth of science, switches the focus of attention from the merits of a single theory to the relative merits of competing theories. It gives a dynamic picture of science rather than the static account of the most naive falsificationists. Instead of asking of a theory, "Is it falsifiable?", "How falsifiable is it?" and "Has it been falsified?", it becomes more appropriate to ask, "Is this newly proposed theory a viable replacement for the one it challenges?" In general, a newly proposed theory will be acceptable as worthy of the consideration of scientists if it is more falsifiable than its rival, and especially if it predicts a new kind of phenomenon not touched on by its rival.

The emphasis on the comparison of degrees of falsifiability of series of theories, which is a consequence of the emphasis on a science as a growing and evolving body of knowledge, enables a technical problem to be bypassed. For it is very difficult to specify just how falsifiable a single theory is. An absolute measure of falsifiability cannot be defined simply because the number of potential falsifiers of a theory will always be infinite. It is difficult to see how the question, "How falsifiable is Newton's law of gravitation?" could be answered. On the other hand, it is often possible to compare the degrees of falsifiability of laws or theories. For instance, the claim, "All pairs of bodies attract each other with a force that varies inversely as the square of their separation", is more falsifiable than the claim, "The planets in the solar system attract each other with a force that varies inversely as the square of their separation". The second is implied by the first. Anything that falsifies the second will falsify the first, but the reverse is not true. Ideally, the falsificationist would like to be able to say that the series of theories that constitute the historical evolution of a science is made up of falsifiable theories, each one in the series being more falsifiable than its predecessor.

2. Increasing falsifiability and *ad hoc* modifications

The demand that, as a science progresses, its theories should become more and more falsifiable, and consequently have more and more content and be more and more informative, rules out modifications in theories that are designed merely to protect a theory from a threatening falsification. A modification in a theory, such as the addition of an extra postulate or a change in some existing postulate, that has no testable consequences that were not already testable consequences of the unmodified theory will be called *ad hoc* modifications. The remainder of this section will consist of examples designed to clarify the notion of an *ad hoc* modification. I will first consider some *ad hoc* modifications, which the falsificationist would reject, and afterwards these will be contrasted with some modifications that are not *ad hoc* and which the falsificationist would consequently welcome.

I begin with a rather trivial example. Let us consider the generalization, "Bread nourishes". This low-level theory, if spelt out in more detail, amounts to the claim that if wheat is grown in the normal way, converted into bread in the normal way and eaten by humans in a normal way, then those humans will be nourished. This apparently innocuous theory ran into trouble in a French village on an occasion when wheat was grown in a normal way, converted into bread in a normal way and yet most people who ate the bread became seriously ill and many died. The theory, "(All) bread nourishes", was falsified. The theory can be modified to avoid this falsification by adjusting it to read, "(All) bread, with the exception of that particular batch of bread produced in the French village in question, nourishes". This is an *ad hoc* modification. The modified theory cannot be tested in any way that was not also a test of the original theory. The consuming of any bread by any human constitutes a test of the original theory, whereas tests of the modified theory are restricted to the consuming of bread other than that batch of bread that led to such disastrous results in France. The modified hypothesis is less falsifiable than the original version. The falsificationist rejects such rearguard actions.

The next example is less gruesome and more entertaining. It is an example based on an interchange that actually took place in the seventeenth century between Galileo and an Aristotelian adversary. Having carefully observed the moon through his newly invented telescope, Galileo was able to report that the moon was not a smooth sphere but that its surface abounded in mountains and craters. His Aristotelian adversary had to admit that things did appear that way when he repeated the observations for himself. But the observations threatened a notion fundamental for many Aristotelians, namely, that all celestial bodies are perfect spheres. Galileo's rival defended his theory in the face of the apparent falsification in a way that was blatantly *ad hoc*. He suggested that there was an invisible substance on the moon, filling the craters and covering the mountains in such a way that the moon's shape was perfectly spherical. When Galileo inquired how the presence of the invisible substance might be detected, the reply was that there was no way in which it could be detected. There is no doubt, then, that the modified theory led to no new testable consequences and would be quite unacceptable to a falsificationist. An exasperated Galileo was able to show up the inadequacy of his rival's position in a characteristically witty way. He announced that he was prepared to admit that the invisible undetectable substance existed on the moon, but insisted that it was not disturbed in the way suggested by his rival but in fact was piled up on top of the mountains so that they were many times higher than they appeared through the telescope. Galileo was able to outmanoeuvre his rival in the fruitless game of the invention of *ad hoc* devices for the protection of theories.

One other example of a possibly *ad hoc* hypothesis from the history of science will be briefly mentioned. Prior to Lavoisier, the phlogiston theory was the standard theory of combustion. According to that theory, phlogiston is emitted from substances when they are burnt. This theory was threatened when it was discovered that many substances gain weight after combustion. One way of overcoming the apparent falsification was to suggest that phlogiston has negative weight. If this hypothesis could be tested only by weighing substances before and after combustion, then it was *ad hoc*. It led to no new tests.

Modifications of a theory in an attempt to overcome a difficulty need not be *ad hoc*. Here are some examples of modifications that are not *ad hoc*, and which consequently are acceptable from a falsificationist point of view.

Let us return to the falsification of the claim, "Bread nourishes", to see how this could be modified in an acceptable way. An acceptable move would be to replace the original falsified theory by the claim, "All bread nourishes except bread made from wheat contaminated by a particular kind of fungus" (followed by a specification of the fungus and some of its characteristics). This modified theory is not *ad hoc* because it leads to new tests. It is *independently testable,* to use Popper's phrase.[1] Possible tests would include testing the wheat from which the poisonous bread was made for the presence of the fungus, cultivating the fungus on some specially prepared wheat and testing the nourishing effect of the bread produced from it, chemically analyzing the fungus for the presence of known poisons, and so on. All these tests, many of which do not constitute tests of the original hypothesis, could result in the falsification of the modified hypothesis. If the modified, more falsifiable, hypothesis resists falsification in the face of the new tests, then something new will have been learnt and progress will have been made.

Turning now to the history of science for a less-artificial example, we might consider the train of events that led to the discovery of the planet Neptune. Nineteenth-century observations of the motion of the planet Uranus indicated that its orbit departed considerably from that predicted on the basis of Newton's gravitational theory, thus posing a problem for that theory. In an attempt to overcome the difficulty, it was suggested, by Leverrier in France and by Adams in England, that there existed a previously undetected planet in the vicinity of Uranus. The attraction between the conjectured planet and Uranus was to account for the latter's departure from its initially predicted orbit. This suggestion was not *ad hoc,* as events were to show. It was possible to estimate the approximate vicinity of the conjectural planet if it were to be of a reasonable size and to be responsible for the perturbation of

Uranus' orbit. Once this had been done, it was possible to test the new proposal by inspecting the appropriate region of the sky through a telescope. It was in this way that Galle came to make the first sighting of the planet now known as Neptune. Far from being *ad hoc,* the move to save Newton's theory from falsification by Uranus's orbit led to a new kind of test of that theory, which it was able to pass in a dramatic and progressive way.

3. Confirmation in the falsificationist account of science

When falsificationism was introduced as an alternative to inductivism in the previous chapter, falsifications, that is, the failures of theories to stand up to observational and experimental tests, were portrayed as being of key importance. It was argued that the logical situation permits the establishment of the falsity but not of the truth of theories in the light of available observation statements. It was also urged that science should progress by the proposal of bold, highly falsifiable conjectures as attempts to solve problems, followed by ruthless attempts to falsify the new proposals. Along with this came the suggestion that significant advances in science come about when those bold conjectures are falsified. The self-avowed falsificationist Popper says as much in the passage quoted on p.44, where the italics are his. However, exclusive attention to falsifying instances amounts to a misrepresentation of the more sophisticated falsificationist's position. More than a hint of this is contained in the example with which the previous section concluded. The independently testable attempt to save Newton's theory by a speculative hypothesis was a success because that hypothesis was confirmed by the discovery of Neptune and not because it was falsified

It is a mistake to regard the falsification of bold, highly falsifiable conjectures as the occasions of significant advance in science.[2] This becomes clear when we consider the various extreme possibilities. At one extreme, we have theories that take the form of bold, risky conjectures, while at the other, we have theories that are cautious conjectures, making claims that seem to involve no significant risks. If either kind of conjecture fails an observational or experimental test it will be falsified, while if it passes such a test we will say it is *confirmed.*[3] Significant advances will be marked by the *confirmation* of *bold* conjectures or the *falsification* of *cautious* conjectures. Cases of the former kind will be informative, and

constitute an important contribution to scientific knowledge, simply because they mark the discovery of something that was previously unheard of or considered unlikely. The discovery of Neptune and of radio waves and Eddington's confirmation of Einstein's risky prediction that light rays should bend in strong gravititional fields all constituted significant advances of this kind. Risky predictions were confirmed. The falsification of cautious conjectures is informative because it establishes that what was regarded as unproblematically true is in fact false. Russell's demonstration that naive set theory, which was based on what appear to be almost self-evident propositions, is inconsistent is an example of an informative falsification of a conjecture apparently free from risk. By contrast, little is learnt from the *falsification* of a *bold* conjecture or the *confirmation* of a *cautious* conjecture. If a bold conjecture is falsified, then all that is learnt is that yet another crazy idea has been proved wrong. The falsification of Kepler's speculation that the spacing of the planetary orbits could be explained by reference to Plato's five regular solids does not mark one of the significant landmarks in the progress of physics. Similarly, the confirmation of cautious hypotheses is uninformative. Such confirmations merely indicate that some theory that was well established and regarded as unproblematic has been successfully applied once again. For instance, the confirmation of the conjecture that samples of iron extracted from its ore by some new process will, like other iron, expand when heated, would be of little consequence.

The falsificationist wishes to reject *ad hoc* hypotheses and to encourage the proposal of bold hypotheses as potential improvements on falsified theories. Those bold hypotheses will lead to novel, testable predictions, which do not follow from the original, falsified theory. However, while the fact that it does lead to the possibility of new tests makes an hypothesis worthy of investigation, it will not rank as an improvement on the problematic theory it is designed to replace until it has survived at least some of those tests. This is tantamount to saying that before it can be regarded as an adequate replacement for a falsified theory, a newly and boldly proposed theory must make some novel predictions that are confirmed. Many wild and rash speculations will not survive subsequent testing and consequently will not be rated as contributing to the growth of scientific knowledge. The occasional wild and rash speculation that does lead to a novel, unlikely prediction, which is nevertheless confirmed by observation or experiment, will thereby become established as a highlight in the history of the growth of science. The *confirmations* of novel predictions resulting from bold conjectures are very important in the falsificationist account of the growth of science.

4. Boldness, novelty and background knowledge

A little more needs to be said about the adjectives "bold" and "novel" as applied to hypotheses and predictions respectively. They are both historically relative notions. What rates as a bold conjecture at one stage in the history of science need no longer be bold at some later stage. When Maxwell proposed his "dynamical theory of the electromagnetic field" in 1864, it was a bold conjecture. It was bold because it conflicted with theories generally accepted at the time, theories that included the assumption that electromagnetic systems (magnets, charged bodies, current-carrying conductors, etc.) act upon each other instantaneously across empty space and that electromagnetic effects can be propagated at a finite velocity only through material substances. Maxwell's theory clashed with these generally accepted assumptions because it predicted that light is an electromagnetic phenomenon and also predicted, as was to be realized later, that fluctuating currents should emit a new kind of radiation, radio waves, travelling at a finite velocity through empty space. In 1864, therefore, Maxwell's theory was bold and the subsequent prediction of radio waves was a *novel* prediction. Today, the fact that Maxwell's theory can give an accurate account of the behaviour of a wide range of electromagnetic systems is a generally accepted part of scientific knowledge, and assertions about the existence and properties of radio waves will not rate as novel predictions.

If we call the complex of scientific theories generally accepted and well established at some stage in the history of science the *background knowledge* of the time, then we can say that a conjecture will be bold if its claims are unlikely in the light of the background knowledge of the time. Einstein's general theory of relativity was a bold one in 1915 because at that time background knowledge included the assumption that light travels in straight lines. This clashed with one consequence of general relativity, namely, that light rays should bend in strong gravitational fields. Copernicus's astronomy was bold in 1543 because it clashed with the background assumption that the earth is stationery at the centre of the universe. It would not be considered bold today.

Just as conjectures will be considered bold or otherwise by reference to the relevant background knowledge, so predictions will be judged novel if they involve some phenomenon that does not figure in, or is perhaps explicitly ruled out by, the background knowledge of the time. The prediction of Neptune in 1846 was a novel one because the background knowledge at that time contained no reference to such a planet. The prediction that Poisson deduced from Fresnel's wave theory of light in 1818, namely, that a bright spot should be observed at the centre of one side of an opaque disc suitably illuminated from the other, was novel because the existence of that bright spot was ruled out by the particle theory of light that formed part of the background knowledge of the time.

In the previous section, it was argued that major contributions to the growth of scientific knowledge come about either when a bold conjecture is confirmed or when a cautious conjecture is falsified. The idea of background knowledge enables us to see that these two possibilities will occur together as the result of a single experiment. Background knowledge consists of cautious hypotheses just because that knowledge is well established and considered to be unproblematic. The confirmation of a bold conjecture will involve the falsification of some part of the background knowledge with respect to which the conjecture was bold.

5. Comparison of the inductivist and falsificationist view of confirmation

We have seen that confirmation has an important role to play in science as interpreted by the sophisticated falsificationist. However, this does not invalidate the labelling of that position "falsificationism". It is still maintained by the sophisticated falsificationist that theories can be falsified and rejected while it is denied that theories can ever be established as true or probably true. The aim of science is to falsify theories and to replace them by better theories, theories that demonstrate a greater ability to withstand tests. Confirmations of new theories are important insofar as they constitute evidence that a new theory is an improvement on the theory it replaces, the theory that is falsified by the evidence unearthed with the aid of, and confirming, the new theory. Once a newly proposed bold theory has succeeded in ousting its rival, then it in turn becomes a new target at which stringent tests should be directed, tests devised with the aid of further boldly conjectured theories.

Because of the falsificationists' emphasis on the growth of science, their account of confirmation is significantly different from that of the inductivists. The significance of some confirming instances of a theory according to the inductivist position described in Chapter 1 is determined solely by the logical relationship between the observation statements that are confirmed and the theory that they support. The degree of support given to Newton's theory by Galle's observation of Neptune is no different from the degree of support given by a modern observation of Neptune. The historical context in which the evidence is acquired is irrelevant. Confirming instances are such if they give inductive support to a theory, and the greater the number of confirming instances established, the greater the support for the theory and the more likely it is to be true. This ahistorical theory of confirmation would seem to have the unappealing consequence that innumerable observations made on falling stones, planetary positions, etc. will constitute worthwhile scientific activity insofar as they will lead to increases in the estimate of the probability of the truth of the law of gravitation.

By contrast, in the falsificationist account, the significance of confirmations depends very much on their historical context. A confirmation will confer some high degree of merit on a theory if that confirmation resulted from the testing of a novel prediction. That is, a confirmation will be significant if it is estimated that it is unlikely to eventuate in the light of the background knowledge of the time. Confirmations that are foregone conclusions are insignificant. If today I confirm Newton's theory by dropping a stone to the ground, I contribute nothing of value to science. On the other hand, if tomorrow I confirm a speculative theory implying that the gravitational attraction between two bodies depends on their temperature, falsifying Newton's theory in the process, I would have made a significant contribution to scientific knowledge. Newton's theory of gravitation and some of its limitations are part of current background knowledge, whereas a temperature dependence of gravitational attraction is not. Here is one further example in support of the historical perspective that the falsificationists introduce into confirmation. Hertz confirmed Maxwell's theory when he detected the first radio waves. I also confirm Maxwell's theory whenever I listen to my radio. The logical situation is similar in the two cases. In each case, the theory predicts that radio waves should be detected and, in each case, their successful detection lends some inductive support to the theory. Nevertheless, Hertz is justly famous for the confirmation he achieved, whereas my frequent confirmations are rightly ignored in a scientific context. Hertz made a significant step forward. When I listen to my radio I am only marking time. The historical context makes all the difference.

FURTHER READING

Popper's writings have already been referred to as reading relevant to falsificationism. Especially relevant to discussions of the growth of science is *Conjectures and Refutations* (London: Routledge and Kegan Paul, 1969), Ch. 10 and *Objective Knowledge* (Oxford: Oxford University Press, 1972), Ch. 5 and 7. Feyerabend has made contributions to the more sophisticated falsificationist programme. See, for instance, his "Explanation, Reduction and Empiricism", in *Scientific Explanation, Space and Time, Minnesota Studies in the Philosophy of Science,* vol.3, ed. H. Feigl and G. Maxwell (Minneapolis: University of Minnesota Press, 1962), pp.27-97, and "Problems of Empiricism", in *Beyond the Edge of Certainty,* ed. R. Colodny (New York: Prentice-Hall, 1965), pp.45-260. I. Lakotos discusses various stages in the development of the falsificationist programme and its relation to the inductivist programme in "Falsification and the Methodology of Scientific Research Programmes", in *Criticism and the Growth of Knowledge,* ed. I. Lakatos and A. Musgrave (Cambridge: Cambridge University Press, 1974), pp.91-196, and he applies the falsificationist concept of growth to mathematics in "Proofs and Refutations", *British Journal for the Philosophy of Science* 14 (1963-64): 1-25, 120-39, 221-342. Interesting discussions of the growth of science are Noretta Koertge, "Theory Change in Science", in *Conceptual Change,* ed. G. Pearce and P. Maynard (Dordrecht: Reidel Publ. Co., 1973), pp.167-98; S. Amsterdamski, *Between Science and Metaphysics* (Dordrecht: Reidel Publ. Co., 1975); and H.R. Post, "Correspondence, Invariance and Heuristics", *Studies in History and Philosophy of Science* 2 (1971): 213-55.

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1. See, for example, K.R. Popper, "The Aim of Science", in his *Objective Knowledge* (Oxford: Oxford University Press, 1972), pp.191-205, especially p.193.
2. For a detailed discussion of this point, see A.F. Chalmers, "On Learning from Our Mistakes", *British Journal for the Philosophy of Science* 24 (1973): 164-173.
3. This usage of "confirmed" should not be confused with another usage, according to which to say of a theory that it is confirmed is to claim that it has been proved or established as true.