Harold JEFFREYS
b. 22 April 1891 - d. 18 March 1989

Summary. Harold Jeffreys, a distinguished British geophysicist, advocated and justified the use of probability to describe one's beliefs about scientific ideas, and developed powerful methods for interpreting scientific data through probability.

The career of Harold Jeffreys (1891-1989) is easily described. From his local school in County Durham, he sent up to Cambridge, where he stayed for the rest of his life. His continuous 75 years as a fellow of St. John's College is a record for any Oxbridge college. He was Plumian Professor of Astronomy and Experimental Philosophy, received numerous scientific awards and was knighted.

During most of his life, and certainly up until his retirement from the Chair in 1958, he was best known for his important work in geophysics and related fields. His book, *The Earth: Its Origin, History and Physical Constitution*, is a classic. One of the problems he studied was that of the transmission of earthquake waves through the earth and, in particular, the interpretation of seismological data. As a result, he became interested in statistical problems. This interest was enhanced by the attention paid in Cambridge of the 1920's to the philosophy of science. This combination of philosophy with scientific data culminated in the publication in 1939 of his other great book, called simply *Theory of Probability.* The substantially revised third edition appeared in 1961. It is still in print and is considered by many statisticians to be essential reading, not just for historical reasons, but because of its modern manner of thought. As Barnard said "There are a few [books] that are so far ahead of their time that they are initially neglected and only reach their peak many years after publication". He was a poor oral communicator but his writing is superb. He stands, with literature's greatest, in the effective use of the English language.

There are two major novelties in the *Theory*, as he liked to call his book. The first lies in the concept of probability: the second in the development, from this concept, of practical procedures for handling data. He addressed the problem of how one's uncertainty about quantities of scientific interest, like hypotheses or values of constants, should be described. In the first chapter he demonstrated, on the basis of some simple ideas, in effect used as axioms, that this could only be done through probability; so that one could speak of the probability of a hypothesis being true. Furthermore, statements of these uncertainties had to combine according to the rules of probability. One of these rules is Bayes's theorem and because of its ubiquity, the subject, when treated from this viewpoint, has become known as Bayesian statistics. The theory was the first modern book on Bayesian statistics. This attitude towards probability was quite different from that of his near-contemporary, R.A. Fisher (q.v.), who was, in the 1930s, revolutionizing statistics. Fisher used only the probability of the data, given the hypothesis, whereas Jeffreys was advocating and justifying the concept of the probability of the hypothesis, given the data. Fisher's ideas found general acceptance and Jeffreys was initially treated as a maverick.

Views like Jeffreys's were also being developed by F.P. Ramsey (also in Cambridge) and de Finetti in Italy. They were later to be expounded in the 1950s by L.J. Savage in the States. Jeffreys went further than these workers and developed operational techniques for handling data. Fisher was doing the same and it was possible to compare the two procedures on a data set. At the same time there weemed to be good agreement but later work has revealed important differences which are especially noticeable in the testing of hypotheses. Fisher's tests built on earlier ideas and used the concept of a tail area. If, on hypothesis H, a statistic x has probability density $p(x|H)$, the tail-area probability associated with the observed value x is $\int_x^\infty p(t|H)dt$, sometimes called a P-value, or significance level. Jeffreys proceeded quite differently and in an original argument calculated the probability of H, given x, $p(H|x)$. This was based on a prior probability of H, which he took to be $1/2$. In important numerical cases $p(H|x)$ can differ substantially from the P-value. An advantage of the broader view of probability is that the resulting numbers, unlike p-values, are exactly those required for decision-making. Although Jeffreys, as the pure scientist in his college, never considered decisions, his general treatment has been found effective in management science and other fields.

Jeffreys differed from de Finetti in regarding the numerical value of a probability as being shared by all rational persons, whereas de Finetti thought of it as subjective. According to the latter view, scientific objectivity only arises after substantial amounts of data, relevant to a problem, have drawn differing subjective views into agreement. If Jeffreys was right, he had to have some way of producing the rational probability. The way he explored, and which later workers have followed, is first to describe a rational view of ignorance. If a probability that represented knowing nothing about a quantity, an extreme form of uncertainty, could be developed, then any knowledge could update that probability by Bayes's theorem, to produce rational opinions in the light of that knowledge. Ignorance played the role of an origin. For example, a probability of 1/2 seems to correspond to knowing nothing about whether a hypothesis is true or not, being neutral between the two possibilities. A major advance in the later editions of the Theory was the development of a probabilistic description of ignorance using invariance concepts. Jeffreys was the first to recognise some inadequacies in his suggestions but they have been very fruitful in leading later workers to develop them into what nowadays are called 'reference' or 'default' probabilities.

Jeffreys's views have influenced the philosophy of science, and are in marked contrast to those of Karl Popper, who advocated the view that a hypothesis could only be disproved, whereas probability admitted values near one, effectively amounting to proof. An important illustration of the effect of this probabilistic thinking on social and scientific questions is provided by contemporary studies of global warming. Is it taking place, due to industrial and other pollutants, and, if it is, what will be its magnitude? The probability school would calculate the probability of warming using available data, and the conditional probability of its magnitude, given that it exists. Decisions based on these probabilities can then be made rationally. Generally, discourse on important questions involving uncertainty should be conducted in the language of probability.

Jeffreys worked largely on his own but his earlier, philosophical ideas were developed with Dorothy Wrinch, who later became well-known as an opponent of the ideas of Linus Pauling. In 1940 he married Bertha Swirles. They co-authored a splendid book on *The Methods of Mathematical Physics.* Jeffreys was a great geophysicist who also created an original way of conducting the scientific method.

References

[1] His major statistical work is H. Jeffreys (1961). *Theory of Probability*, 3rd Edition. Clarendon Press, Oxford.

[2] H. Jeffreys & B Swirles (1956). *Methods of Mathematical Physics.* Cambridge University Press, is popularly known as 'Jeffreys and Jeffreys'.

[3] The issue of *Chance* magazine for Spring 1991, **2, #4**, is devoted to him and contains several articles on his life and work, by Lady Jeffreys and others. For other references to Bayesian statistics, see under Thomas Bayes.

D.V. Lindley