How certain is science?

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What is *truth*? What is *reality*? How certain are we regarding any given *fact*? These are questions pondered upon by philosophers from time immemorial. This search for the nature of knowledge has culminated in different epistemic theories of truth. In this note I delve into this aspect in the field of science. Many people outside the field of science often confuse it with certainty. They think that what science says is infallible; its predictions are 100% accurate/reliable. This is perhaps due to the high precision and accuracy with which science predicts different future events like eclipses, time of sunrise and sunset, launching of spacecraft and rockets, etc. However, a close scrutiny will reveal that in the midst of these predictions there are errors and uncertainties involved.

The philosophy of science centres around the principal task of analysing the methods of enquiry used in the field. In science there are two opposing schools of thought – one is called realism and the other is called anti-realism. Realism asserts that there exists a real external world whose properties are definite and independent of the observer who perceives them. The anti-realists, on the other hand, draw a distinction between empirical knowledge and theoretical knowledge. They assert that there is no objective reality. Philosopher George Berkeley (1685–1753), a staunch anti-realist even went to the extent of claiming that nothing exists except the mind and its ideas.

In between these two extreme philosophies there is a middle view which is called model-dependent realism. But what is this model-dependent reality? This is science interpreted as model-making. Scientific knowledge is acquired through an approach called scientific method, which roughly involves observations, hypothesizing, experimentation, theorizing and framing of laws. In the process of theorizing and framing of laws, mathematical techniques and tools are frequently used. The ultimate result is a model: conceptual or concrete; prognosis or diagnosis. In this framework a physical theory or world picture is a model and a set of rules that connect the elements of the model to observations. For example, we had, now defunct, Dalton's atomic model, Ptolemy's model of the universe; and modern models like quantum and string theories. Our understanding of the universe is through these models. It all depends upon how we perceive our surrounding. According to model-dependent realism, it is pointless to argue about reality. So long as the prediction of our model agrees with observation, it is real.

British theoretical physicist Stephen Hawking gave a beautiful example of model-dependent realism in his book, *The Grand Design*[1]. Administration of a particular city of Italy once banned pet owners from keeping gold fish in curved bowls. The reason stated being that the fish get a distorted picture of reality while viewing the world from curve faces of the bowl and it is a form of cruelty to the fish. Now the question is: How do we know that we are getting a correct picture of reality and not the fish? May be our vision is also distorted by some enormous lens. The gold fish can, if sufficiently intelligent, formulate scientific laws governing the motion of the objects by observing from inside the bowl. An object moving in a straight line from our view will appear to move in a curved path for the fish. Nevertheless, the fish will be able to formulate scientific laws from its frame of reference and even predict the future motion of the object outside the bowl. The difference is that the laws framed by the fish would appear to be more complicated in comparison to ours. But our laws may also appear complicated to the fish. So we have no way to determine whose view represents a valid picture of reality. The bottom line is that we perceive of the universe by how we conceive it through our senses or extension of our senses. But we have no way to guarantee that what our senses perceive is real.

Models are for finding plausible answers to our inquiries of the universe around us. Then what is important is not whether a model is real or not, but what matters is that it works. As British statistician George E. P. Box (1919–2013), once mentioned, 'All models are wrong, but some are useful'[2].

The reliability of a model depends on the reliability of the information and evidence we have with us. To take a decision based on the prediction of a model, we need to be aware of the confidence level of the prediction. Thus there lies the importance, need and significance of modelling and quantification of uncertainty. People were aware of uncertainty since time immemorial. But they were not able to clearly understand the nature of different uncertainties. Probability was thought to be the only theory for capturing all sorts of uncertainty. However, after 1960, several new theories of uncertainty distinct from probability theory emerged. Those theories challenged the age-old belief of a unique connection between probability theory and uncertainty. These theories proved beyond doubt that of all the different types of uncertainties, probability theory can capture only one, viz. randomness. Other theories of uncertainty like possibility theory, fuzzy set theory, evidence theory and their hybridization with probability theory are nowadays extensively exploited for uncertainty analysis. First, it is important to identify the nature of the uncertainty. There are two broad categories of uncertainty – aleotary uncertainty and epistemic uncertainty. Aleotary uncertainty is due to randomness and usually non-reducible, whereas epistemic uncertainty occurs basically due to lack of data and is reducible to a certain degree. However in practice, these two uncertainties may occur in combinations. While modelling a situation, all the aspects associated with the phenomenon cannot be incorporated in the model and as such this results in another form of uncertainty which goes by the name of model uncertainty.

The dynamic and evolutionary nature of science emphasizes the uncertainty aspect of its nature. A glimpse into the history of science will help us appreciate this. We have ample instances where scientific theories are modified or even replaced by new ones. With each model or theory, our concepts of reality and of the fundamental constituents of the universe change. From Aristotle's idea that the world is made of only four elements, viz.

earth, air, water and fire, to Newton's classical theory that all laws of nature are deterministic, to the present-day quantum theory and string theory, there has been a sea change in our understanding of the universe. Let us take a recent instance. Two Nobel Prizes were awarded for discoveries which later were partially disproved[3]. In 1927, German chemist Henrich Wieland (1877–1957) received the Nobel Prize in Chemistry for discovering the structure of cholic acid, the parent substance from which he derived a large number of important chemical compounds such as cholesterol. However, a part of this structure was proved to be wrong soon afterwards. In 1959, two American biochemists, Severo Ochoa (1905–93) and Arthur Kornberg (1918–2007), received the Nobel Prize in Physiology or Medicine for the discovery of enzymes which carry out the synthesis of nucleic acids – the chemical substance responsible for heredity. Later, it turned out that neither of the two enzymes discovered by Ochoa and Kornberg was responsible for the synthesis of nucleic acids in living systems.

A deliberation on uncertainty in science cannot be complete without the mention of the American theoretical physicist Richard Phillips Feynman (1918–88). According to him, all scientific knowledge is uncertain. In other words, science is a body of statements of varying degrees of certainty; some of these may be almost sure, but none is absolutely certain[4]. That Feynman was so certain about uncertainty was expressed in his words as: It is impossible to find an answer which someday will not be found to be wrong[5]. He emphasized not only the science of uncertainty but also advocated a philosophy of ignorance/uncertainty to better appreciate and comprehend science. He argued that freedom to doubt is essential for the progress of science.

The uncertainty aspect of science can similarly be discussed and extended to other fields of knowledge. In fact, uncertainty is pervading many aspects of our life and almost all branches of knowledge. A belief in absolutism is a dangerous phenomenon as it begets intolerance. Questions like 'what is good'? 'what is bad'?, 'what is right'?, 'what is wrong'?, etc. are open for debate and discussions. It all depends on the perspective from which we judge good/bad, right/wrong, etc. Thus in most cases, these are relative and only a matter of conviction only. As German philosopher Friedrich Nietzche (1844–1900) said: There are no facts, only interpretations[6].

To conclude we may add what British philosopher and mathematician Bertrand Russell had said: Not to be absolutely certain is, I think, one of the essential things in rationality[7]. The bigger question is whether there is an absolute reality or not. And if there is any, shall we be able to perceive it?

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3. Bhargava, P. M. and Chakrabarty, C., *Angels, Devil and Science*, NBT, 2007.
4. http://www.inf.fu-berlin.de/lehre/pmo/eng/Feynman-Uncertainty.pdf (accessed on 4 October 2016).
5. Feynman, R. P., *The Pleasure of Finding Things Out*, Helix Books, New York, 2005.
6. Clark, M., *Nietzsche on Truth and Philosophy*, Colgate University, Cambridge University Press, Cambridge, UK, 1990.
7. Russell, B., *Am I an Atheist or an Agnostic? A Plea for Tolerance in the Face of New Dogmas*, Literary licensing, LLC, Whitefish, USA, 2011.

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Possible implications of a recent gazette notification on *Bt*-cotton scenario in India

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According to a new Central Government gazette notification S.0.1813 (E) dated 18 May 2016, titled 'Licensing and Formats for GM Technology Agreement Guidelines, 2016', significant changes were proposed by the Ministry of Agriculture, that if implemented could have had far reaching consequences on cotton scenario in India. However, the Ministry suspended the gazette on 24 May 2016 and invited public comments within 90 days for a possible re-consideration and revision. It remains to be seen, as to which aspects of the gazette would be retained that may re-shape policies which could have a positive influence on the cotton sector.

Bt-cotton contains one or more genes derived from the soil bacterium *Bacillus thuringiensis* and introduced into the cotton genome through genetic modification (GM). The genes express insecticidal proteins in the plant parts and are generally referred as Cry (crystal) proteins which are toxic to leaf-eating caterpillar pests, more specifically to the three species of cotton bollworms. '*Bt*-cotton' event Mon-531 (*cry1Ac* gene) was first approved by the Genetic Engineering Approval Committee (GEAC), Ministry of Environment, for commercial cultivation in India on 26 April 2002. Subsequently in 2006, three new *Bt*-cotton GM events, namely MON-15985 (Bollgard-II®, *cry1Ac* + *cry2Ab2* genes), event-1 (*cry1Ac* gene) of JK seeds and GFM event (fusion gene with *cry1Ab* + *cry1Ac* sequences) of Nath seeds were approved for commercial cultivation. *Bt*-cotton event BNLA-601 of UAS Dharwad was approved in 2008 and event MLS-9124 of Meta-Helix Life Sciences was approved in 2009. So far six *Bt* cotton events have been approved for commercial cultivation in India and are being marketed by 49 Indian seed companies under licence agreements from Monsanto. Though six different *Bt*-cotton events have been approved thus far in India, currently more than 95% of the cotton area in the country is covered by