A Current Perspective on Science, Scientists and "Scientific Temper"- Busting Myths and Misconceptions

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Abstract

This article is devoted to define and characterize 'Science' as a discipline by the fundamental principles of scientific investigation. In particular, we propose and argue that 'Science' be defined by a set of principles / criteria which underlies scientific- investigation. We argue that this set must include the following principles: (1) Rationality, (2) Objectivity (3) Universality, (4) Internal Consistency, (5) Uniqueness, (6) Reproducibility, (7) The Principle of Falsification, (8) Simplicity and Elegance and (9) Experimental Observation and Verification. We elaborate, through illustrative examples, the justification of the above set of criteria. `Scientific temper' essentially means the cultivation of these principles, as attitudes / value-system adopted as "ways of life". We discuss the relevance of the inculcation of scientific temper in the modern context. Finally, the scope and limitations of the scientific method are highlighted and an attempt is made to dispel several misconceptions and myths associated with Science and scientists.

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1. Introduction

In recent times, the methodology of science, its epistemic content and the relevance of the scientific-outlook have been promoted with increasing emphasis [1,4], particularly in the context promoting scientific values for social benefit. Understandably at the same time, there has been also strident criticism [2,3] regarding the fall-outs of the products of science and its perceived adverse effects on human developments. However, both the adversaries and the protagonists have come to agree on one point - namely, the profound effect "science" and its "products" have had on the day-to-day life of an average individual in the modern society - both in terms of achieving material comforts and in terms of modifying the very thinking-process and the mind-set. Of late, the "scientific method" has been advocated to be relevant in the pursuits of knowledge in diverse areas [4] such as History, Literature, Economics, Political-"science", Home-"science" and social-"sciences". Some of these disciplines were considered as totally alien to and beyond the domain of "Science". Hence, it is natural to ask how and why such disciplines could be considered to belong to the realm of "Science". Consider, for example, the case of "Mathematics", "Psychology", or even, "Homeopathy". Do these disciplines qualify to be classified under "Science"? More generally, therefore, it becomes imperative to find out the "necessary" (and "sufficient") set of criteria which could serve as discriminating tests for distinguishing pure - "Science" from "pseudo"-science, and "non-science" disciplines. This is a prominent motivation for the present article.

Further, it is advocated by many exponents [2,4] that the inculcation and promotion of "scientific values" and "scientific temper" could be an essential requirement, which may ultimately prove to achieve the desired goal of universal brotherhood in a "global" society devoid of rancor, conceit and conflict. There is also a growing belief that the systematic, analytical, rational and objective approach to problems, which are the hallmarks of the scientific method, may be of primary help in solving the sundry problems of life, vocation and of the society at large.

On the other hand, there are also many who believe that "science" has robbed the essence of life in rendering the "scientific man" cold, mechanical, aloof and almost a robot- like weird creature devoid of the characteristic human emotions and feelings. There is also growing "superstition" that scientists are infallible and are super-human beings in their capabilities. Again, it is believed by many that principles of science are so abstruse that they are doomed to remain incomprehensible to the general populace. Moreover, there is also much expressed concern for the perceived adverse sociological impact, tendency towards an overt materialistic approach towards life and various other ill effects of the fall-outs which science has brought along. It could well be that these criticisms are often based on wrong premises of confounding the *by-products and the applied aspect of science* with the *basic methodology* which defines the latter and which is promoted as a value -system.

It is the purpose of this article to address, expand and expound on some of the above issues on the relevance of the "scientific method" in the modern context.

2. Defining Science

Although too common a word in current usage, it is basic to first define what "Science" means before one can embark on an exposition of the scientific method. A currently accepted **definition** could be:

"Science is the systematic study and investigation of ***Nature*** *through* ***observation, experimentation*** *and* ***theorizing*** *in order to arrive at an* ***understanding*** *of natural phenomena".*

In the above context, "Nature" as we perceive it, may be regarded to consist of both the "manifest" and the "latent" components. It is almost an *axiom*, in pursuance of the scientific method, that the physically manifest-component of nature is comprehensible, amenable to perception and logical exposition. At the same time, the "latent" component of nature is recognized to exist and considered to be incomprehensible to human perception (It may, however, be accessible to human *intuition*!). However, it is hard to escape the conclusion, established *by the method of science itself* that existence beyond human-perception cannot be ruled out. We shall attempt to provide some plausible arguments in favor of this hypothesis later in this article. It is sufficient at this point, however, to proceed with the above assumption and base the methodology of science in relation to the *observable* Universe.

It may be useful to start with tracing the *history of the development of the discipline*, which we now regard as "modern-science". It is universally believed that intellectual enquiry into the laws governing the observable universe was the starting point of the scientific endeavor. The transition from the "deductive" to the "inductive" basis [5] of "science" was probably the most important development. This transition was made when the decisive role of observation and experiments was inducted into the formulation of the discipline. The common-sense and experience-based inevitable assumptions which formed as "axioms" in the "deductive" approach were challenged and most often discarded in favor of the "experimentally-established laws" which then formed the basis of the "inductive" approach. In the deductive- formulation, the disciplines such as "Natural Philosophy" and "Metaphysics" etc, generalized to include also "mathematics", were considered indistinguishable from "science". However, the advent of the revolution, which emphasized the crucial role of observation and "experimentation" as the most important ingredients, resulted in the transition from the "deductive" to the "inductive" basis [5] of "science". This transition may, therefore, be considered the turning point in defining Science and its methodology. To illustrate this fundamental historical development, the following few well-known examples may perhaps suffice:

The legendary experiment of Galileo from atop the leaning tower of Pisa exploded the myth hitherto accepted as an obvious "truth" that heavier bodies fall to the ground quicker than lighter ones when dropped from the same height (A modern version of this experiment, i.e. "The Hammer-Feather Experiment" was performed by astronauts in space). Such an 'axiom' was, of course, based upon common experience that a piece of paper/feather floats down to earth taking considerably more time than a ball of iron dropped from the same height. Galileo's experiment showed that this happened for totally different reasons, i.e. due to air resistance and viscosity rather than the weight of the paper because the same piece of paper when crumpled into a ball took considerably less time to fall to the ground!

Consider next a second example:

In spite of the every-day observation that the sun rises in the east, "moves" in the sky and sets in the west, no one now believes in the " Geocentric Theory " i.e. that the earth is static while the sun revolves around it! This realization, although so obvious to the "common-man" now, took ages to take root through the scientific method of experimentation!

Similar is the case regarding the belief that the earth is flat!

The present incarnation of "modern science" is founded on the *supremacy* of experimental observation and verification. Galileo, Newton and many other stalwarts pioneered this approach.

Consider next the history of "scientific inventions". It is commonly accepted that the first scientific "inventions" were made *out of necessity* of survival, e.g. use of fire, the invention of the wheel, the lever and sharp weapons / instruments for hunting/ cutting etc. The same urge has continued through the ages providing the *motivation for harnessing nature for human needs, comfort and sometimes, for achieving dominance and subjugation!* This aspect of progress of *applied* science highlights a totally different dimension wherein the motivating force is driven by material needs rather than by *purely intellectual enquiry in to the laws and mysteries of nature.* Understandably, a raging debate continues even now as to which of the above two approaches to "scientific progress" is more *relevant!*

3. The Principles underlying the Scientific Method [6,7]

There are certain universally accepted norms and principles, which characterize the basic methodology of scientific-investigations. We list in the following some of these principles. It must be pointed out that the list is neither exhaustive nor complete. However, we believe that the principles enumerated below are certainly *representative*. We discuss these in the following:

- **Objectivity**

The principle of *objectivity,* a basic requirement in scientific investigations, is best understood as opposed to *subjectivity.* The latter depends on personal judgment and , therefore, not free from beliefs, prejudices, faith, dogma and dictums held by individuals, whereas the former is characterized by the *impersonal, measurable and universal method.* A hallmark of the objective approach is that it is quantitative, precise and unambiguous. It is no wonder therefore, to find that *the language of all scientific enquiries is Mathematics – there cannot be two opinions on the validity of a mathematical truth!* The other aspect of objectivity mentioned above is the precise quantitative formulation (*"quantification"*). To illustrate this better, let us analyze the following statements: *(a) The sun is far from us. (b) Rose is beautiful! (c) The earth rotates around its axis.*

In the absence of a defining standard of beauty (*"beauty lies in the eyes of the beholder!"*- hence a totally subjective criterion) or distance (e.g. the earth-sun distance could be negligible compared to inter galactic-distance!), the first two statements cannot be considered as objective statements while the third is a precise quantitative statement satisfying the criterion of objectivity. Thus we see that the essential tools of the objective approach are based upon the method of standardization, benchmarking and precise quantitative statements.

- **Rationality**

The other basic principle underlying the method of science is *Rationality.* According to this principle, scientific formulations need to be based upon logical analysis. Thus, approaches based upon faith, dogma, beliefs, superstitions and dictums (By e.g. Moral authority, Bible, Scriptures ….) are ruled out. In this sense, the principles of objectivity and rationality share common ground. It must be emphasized that *heterodoxy* and *skepticism* become corollaries of the rational, analytic approach and that these have often led to major discoveries and inventions in science throughout its history of development [4].

- **Universality**

In the context of the methodology of science, universality means that scientific-truth, laws, theories are invariant in respect of spatial locations – laws which hold good, say at London, are also true at any other location, say at Australia. Similarly the validity of scientific -truth holds at all times until, of course, newer Laws/ principles are scientifically established to replace the existing ones. The history of scientific developments are replete with examples that have demonstrated the discovery of further generalizations over time, of a given formulation in order to extend the domain and scope of applicability.

There is a second dimension to the principle of universality in the context of practice of scientific collaborations – *scientists form a universal community.* It has been demonstrated that advances in science necessarily require multi - human, multi-national effort transcending the barriers of caste, creed, religion, governance, social- practices and ethos - even the greatest inventions, discoveries or formulation by the stalwarts, having revolutionary consequences have *necessarily* relied upon earlier works by others. In this sense scientific progress is a continuous and inter-linked *global endeavor.* Moreover, the experimental facilities, which are required to probe the fine substructure of matter as in particle-physics experiments, can no longer be established without truly international collaboration at a large scale. An apt example of *globalization* is the invention of the global network: "world-wide-web"(www) at the International laboratory, CERN at Switzerland in 1989, which arose purely from the necessity of speedy international communication of experimental data and results.

- **The Falsification-principle**

This principle is, perhaps, among the most important characteristics in the methodology of modern science- it means that no theory can be regarded as complete and ultimate – *it is a myth to assume that at any given time scientific-truth represents the absolute and the ultimate truth. Even though thousands of experimental data/ observations may be compatible with a given established theory, the possibility exists that a single future experimental data in contradiction with it may falsify the theory!* It is therefore, an essential requirement that a formulation of a scientific theory while explaining the available mass of experimental data, must also provide characteristic predictions, which a future experiment may be able to establish or discard. In this sense, scientific-formulations are always considered to be provisional and *open* for refinement and generalization. This aspect of openness is perhaps singularly responsible to render the scientific-endeavor as interesting and challenging!

- **Internal Consistency / self-consistency**

This principle requires that at no intermediate stage of the formulation of a theory, the results should contradict the basic underlying assumptions. Moreover, the *different input* assumptions must be compatible with each other. Demanding the internal consistency of a formulation has led to new insights into a problem as well as resulting in fresh discoveries. The case of the prediction of the existence of antimatter by Dirac can be cited as a prominent example, which appeared like science-fiction at the time of its prediction but was brilliantly confirmed later by experimental discovery of the "positron" (the anti-particle of the electron) in 1932. There are many more examples: the bending of sun-light while passing through a strong gravitational field as predicted by the general theory of relativity, the prediction of the pi- mesons as carrier of nuclear force, and the prediction of $W^{\pm}$ and the Z^{0} particles as the carrier of the electro-weak forces and the existence of Higgs-Boson constitute brilliant demonstrations of the predictive power of theories based upon self-consistency which were subsequently confirmed by experiments.

- **Experimental verification**

Experimental verification plays the central role in the modern formulation of any scientific investigation. We have earlier remarked how the transition in the methodology of science from the deductive- to the inductive approach took place by the pioneers (Galileo, Archimedes, Newton,….) who established the supremacy of experimental observation and verification of hypotheses in establishing a scientific truth. Any formulation remains either as a *hypothesis* or as a *model* unless it emerges unscathed from a rigorous confrontation with all possible experimental data within the domain of its applicability - only then a formulation is elevated to the status of a *theory*. (It may be pointed out here, the distinction between a "hypothesis" and a "model" – the current usage is that the former is merely a theoretical formulation awaiting experimental verification whereas the latter is able to explain, at least to some extent, the bulk of the experimental data.)

- **Reproducibility**

This is a criterion imposed upon the acceptance of experimental results. Results of a given experiment become credible and acceptable only when these are reproduced (within experimental errors) by experiments independently conducted by different groups at different times. It is not uncommon to find in recent times, several claims of new discoveries being discarded by the scientific community on the ground of the principle of reproducibility- the claim of the discovery of 'cold-fusion' can be cited as a prominent recent example.

- **Uniqueness:**

If two or more formulations explain the same set of facts/ data then there must be a method to discard all but one on some general principle. Such a principle could, for example, be based either on some experimental requirement such as, explaining the broadest range of experimental data or some general theoretical principle which selects out the unique theory from the competing ones.

- **Simplicity and Elegance**

In general, "simplicity" and "elegance" may be regarded as 'subjective' criteria. In order to be consistent with the principle of "objectivity", the criteria of simplicity and elegance are formulated in respect of the underlying mathematical formulation with minimal assumptions ("Ocam's Razor") and elegance. These criteria have been recognized as a "guiding principle" leading to the "correct" theory, which has withstood the test of time. Thus, i*t may not be pure coincidence that the most profound laws have extremely simple and elegant expressions or can be made so through the choice of suitable symbolisms and notations*. Some examples given below may be illustrative:

Consider, for example, the following celebrated equations from the field of Physics:

$\mathbf{F = ma}$ (1), $\mathbf{E = mc^2}$ **(2)**, $\boldsymbol{\lambda = h/p}$ **(3)**, $\mathbf{i\hbar\, \partial\psi/\partial t = H\psi}$ **(4)**, $\partial_\mu \mathbf{F}^{\mu\nu} = \mathbf{j}^\nu$ **(5)**, $\mathbf{F}^{\mu\nu} \equiv \partial^\mu \mathbf{A}^\nu - \partial^\nu \mathbf{A}^\mu$ (6).

The first equation above (Newton's 2nd Law) summarizes perhaps the entire subject of particle- mechanics while the second equation following from the principle of special-theory of relativity expresses the profound relation between mass and energy. Similarly, the next two equations from the realm of quantum theory depict respectively the "wave-particle duality" of physical matter and the "dynamics of quantum theory". The last two equations present examples of how expressions can be brought into elegant forms through the use of "unifying mathematical symbolisms and notations"- in these cases, the tensor notation in special theory of relativity in this case. These latter two expressions ("Maxwell's equations" and the "Constitutive-relations") actually stand for *six* equations in compact notation and govern the whole phenomena of electro-magnetism. *In spite of their expressed simplicity, it may not be an exaggeration to state that each of these equations have ushered in revolutions in the formulation of physical science!*

4. Scientific Temper- Different Aspects

Of late, this phrase has been much in use [2]. It basically means the approach to the problems of life, vocation and society at large,employing the outlook and temperament influenced by the above principles. Collectively, the principles of the scientific method of enquiry can be used to define a value-system.

The approach employing objectivity, rational thinking, precision and exactness etc., in contrast to that based upon of subjective criteria such as faith, prejudice, superstition and dogma etc characterize the scientific temperament. The scientific temperament is further distinguished by the absence of ambiguity, verbosity and redundancy. The ideal scientific man has an *open mind* and a broad outlook- he is amenable to refinement of judgments, as a result of being constantly enlightened and refreshed by the advent of newer and newer scientific vistas. Besides, as we have already pointed out, the vastness of the scientific knowledge and the intricacies and implications of the revealed truth of nature often endow the knowledgeable with a sense of humility.

In particular, consider our own existence in the vast expanse of the Universe. It is scientifically established that the dimension of the Earth is next to negligible (worse than a speck of dust!) in the "cosmic-scale" (e.g. compared to the size of the Universe or even Galactic-distances) and further that humans constitute a minute fraction of living species on Earth. *Yet, when combined with the fact that the above 'truth' is established by the reach of the human intellect through the method of Scientific enquiry, one is led to loaded implications - it completely changes the perspective on ourselves and more importantly, reorients the priorities / responsibilities before us !*

5. The limitations of Science and Scientists [5]

Several myths and misconceptions are currently prevalent as regards to the scope and domain of applicability of science as well as, regarding the capabilities of scientists. Consider, for example, the often-made claim that the "scientific truth", represents the *actual and the ultimate truth.* Similarly, it is also commonly believed by many that scientists are endowed with super-human capabilities. Both these claims and beliefs are certainly debatable.

As is common with any human endeavor, achievements of science as well as capabilities of scientists are certainly limited. We discuss and list in the following, what we believe, are the origin of such limitations:

- *Laws of science are not derivable but empirical*

The *fundamental* laws of Nature are *not* derivable but are arrived at empirically through observation and analysis. The origin of the fundamental laws is bound to remain forever a mystery, which constitutes the inherent limitation of the scope of science. *In this sense, therefore, it is an enormous misconception that the ultimate truth is accessible to science.*

Consider, for example, the law of gravitation that every material body attracts every other, governed by the inverse-square law. It is recognized that this law has a fundamental status in the sense that it does not follow from any other law still more fundamental- rather the law is based upon observation. Similar is the case, for example, with the Newton's law, Laws of Maxwell and laws of Thermodynamics etc. The first step in the scientific investigation is to discover all such fundamental laws by way of observation and analysis of natural-phenomena and secondly, the *ultimate* aim is to relate/ explain all observed natural – phenomena in terms of the fundamental laws.

- *Limitation imposed by the human-sensory perception of the observable universe*

Method of science is applicable to the manifested and the observable universe. Moreover, scientific truth is based upon experimental verification. Both these aspects may be considered as inherent limitations. Consider the first aspect: it is certainly reasonable to assume that the entire universe may not be restricted to what we observe and what we can observe even with the aid of the most sophisticated instruments imaginable. *The very method of scientific analysis, logic and rationality can be applied to infer the existence of a latent, unobservable universe beyond the comprehension of human mind and sensory perception.* There is no compelling reason to believe that human faculties of thinking and perception may have attended the ultimate perfection. It is now established beyond doubt that the development of the human intellect is the result of an evolutionary process. In certain cases even the lowly creatures exhibit faculties of perception, which are superior to those of the humans. Consider, for example, the ultrasonic emission and detection capabilities of the common bat- it "sees" by echo-location!

Similarly, the physical space is three-dimensional as it appears to the human perception. However, the ant or any crawling insect has no sense of the third dimension! Generalizing along similar lines, as also on the basis of purely statistical considerations, it cannot be ruled out that supra-human intelligence might exist in the vast expanse of the Universe. To these creatures, our observable world may look entirely different.

It may be noted that through the invention of sophisticated instruments, the observational capabilities have been substantially improved. Existence of phenomena, which can not otherwise be manifest to the direct sensory perception of sound, sight, touch, smell and taste, have been established through *secondary* effects. The existence of electrons, radio waves or, for that matter, of "quarks", has been established this way. It must be remembered however, that the ultimate detection/ observation finally involves either the sight of a flash of light, a swing of a needle or recording of a sound etc in the instrument or the detector. Thus, the result of experiments is ultimately tied up to the limitations of human sensory perception!

- *Scientists are as much prone to human-errors and possess attitudes and tendencies of any ordinary individual*

The practice of any discipline or any enterprise of knowledge inevitably suffers from the limitations of the practitioners- Science and scientists are no exceptions. Even a cursory glance at the history of science reveals that at times even the stalwarts of science have committed monumental errors! Nevertheless, it goes to the credit of the scientific methodology as a multi- human effort that such mistakes have been often quickly discovered and that science has been the ultimate gainer in the process. It is absurd to associate super-human attributes to scientists- they suffer from the common limitations and traits of human thinking process and behavior. For example, in spite of the acclaimed principle of objectivity and rationality as the hallmark of the scientific methodology, scientists are often found to be holding rigid views based upon faith and prejudice. Similarly, *intuition has played a profound role in the prominent scientific discoveries and inventions.* The study of the sociology of scientists and the practice of science has indeed proved to be a very fascinating and revealing exercise. However, in spite of these limitations, the practice of science being a multi-human enterprise, it has built-in self-correcting mechanism, which ensures that the basic ideals and principles are adhered to.

6. Summary and Conclusions

Before concluding, we summarize the main thrust of this article. It has been argued that the methodology of science is based upon several principles, which can be promoted as a value-system for the general benefit of human society. The approach to problems of life and vocation based upon objectivity, rationality and precise quantitative analysis has a much better chance of success than that based upon subjective considerations characterized by blind faith, prejudices, superstitions and dogma. The open-minded approach of a scientist can create an atmosphere of tolerance to the "other point-of-view" which is considered conducive in the post-modern society for peaceful co-existence in spite of differences of opinion.

Contrary to popular belief, the enormity and intricacies of the acquired scientific knowledge tends to imbue the practitioner with a sense of humility rather than that of arrogance and conceit. Pursuit of science being a global and concerted endeavor, it contains the seeds of ultimate realization of a humane and universal society *not* influenced by nationality, religion, faith and prejudices.

However, in spite of the lauded virtues as succinctly discussed above, there are limitations in the scope of application of science and its methodology. These arise essentially from the obvious reason that science remains a human pursuit and is therefore fraught with the inherent limitations of the human faculties. *It is a common misconception that the abstract and ultimate truth can be established through the process of scientific investigation because there is no such concept as: "ultimate truth" defined in science because the basic laws of science must remain forever empirical and unexplained.*

Similarly it is a myth that Scientists are super human and infallible. A glance at the history of science will reveal that the path to epoch-making discoveries and theories have often been fraught with committing mistakes (and at times, silly mistakes!). Nevertheless, these limitations are recognized as integral part of the process of investigation; they do provide the motivating force and challenge to push the human thinking process to its optimal level of efficiency and thus render the activity all the more interesting.

It must be kept in mind that pursuit of science is identified with acquisition of pure knowledge and remains therefore an intrinsic and universal attribute of the human thinking process independent of the social environment. In that sense, pursuit of pure science remains an exercise purely for sake of creativity and knowledge in close parallel with the pursuit of the creative arts (*"Art for art's sake"*).

In that point of view, the debate for "social relevance of science or of creative arts" becomes mostly redundant- the fundamental scientist can be likened to the ancient sage in the forest/ caves engaged in acquisition of intuitive wisdom through meditation and penance.

On the other hand, *Technology* is concerned with application of science and is geared to meet the needs and demands of a society, a Nation or a State. Many a times it may therefore become an instrument used not only for ensuring a better quality of life but also for subjugation, dominance or hegemony as long as these latter remain as human traits. As has been remarked earlier, confounding of fundamental science with technology has led to considerable confusion. We believe that the spate of current criticism is mostly directed against some perceived adverse effects of the technological onslaught in the post-modern era rather than on the basic methodology of pure science.

What could be the fall-out of this knowledge? One immediate implication could be the *demonstration of the typical role of Science in fixing our perspective on ourselves.* For example, one cannot but feel *humble* in the cosmic plan of things. The vanity, conceit, arrogance and petty squabbling so much in display among each-other; between societies and nations become, for a moment, entirely irrelevant. This could very well be an apt example of how scientific knowledge endows one with a sense of purpose to persist for a greater cause underlying one's existence.

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