Reflections

The Scientific Enterprise

1. Science: Some Definitions and Views

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Modern science is less than four and a half centuries old. Its accomplishments in terms of furthering human knowledge and understanding of the physical and biological world have been stupendous. Science has had other major impacts as well on human civilization. It had its seeds in various cultures of the world: Greek, Indian, Chinese, and Islamic. But it first germinated in Western Europe and then over the centuries it has spread to other parts of the world.

Unfortunately, from the sixteenth to the nineteenth centuries, imperialistic Europe invaded and plundered many peoples in all the continents. And so, though during the past century and a half, science has also spread from the West into the Non-West, the historical anger against Western colonialism has created negative attitudes towards modern science in the minds of many people, prompting them either to reject modern science as a Western colonialist construct, by arguing about its limitations, or by seeking modern science in their own ancient traditions. Such reactions, though understandable in cultural terms, reflect deep misunderstanding of what science is all about. Modern science is neither Western nor colonialist: It is a human enterprise that seeks to unravel every aspect of the physical universe. The scientists of the world form an international fraternity that transcends race, gender, religion, and nationality.

India has already made a significant mark in international science and has an even greater role to play in the current century. In this context, aside from science as a technical field, it would be helpful for India's budding scientists in our colleges and universities, to reflect upon science as a human enterprise, and as a lofty expression of the human spirit. This is the motivation for this series.

Meaning and Etymology of the Word *Science*

The word *science* with its current meaning is of fairly recent usage in the English language. The word occurs with different spellings (*sienz, syense, cience,* etc.) in medieval English with the general sense of *knowledge*. German and Dutch, which belong to the same linguistic family as English, use the words *Wissenschaft*, *wetenschaap*, which are abstract nouns of the verb *to*

know. English is the only non-Romance language which uses a word of Latin derivation for science. The etymology of the word may be traced to the Latin *scientia* which simply means *knowledge*. But in the classical world, the meaning of 'scientific inquiry' was the study of 'nature of things' . With this connotation science began to include all domains of knowledge. Gradually, anything that was not a part of science came to be regarded as knowledge of a lower or less significant variety. This is one of the root causes of conflicts between and controversies about science and religion in our own times. We recall that the Sanskrit word for science is *vijñâna*, which is related to the act of discerning and understanding.

With the rise of modern science in the sixteenth and seventeenth centuries, the more common term for science was *natural philosophy*. In other words, science was essentially the philosophy of, or systematic inquiry into, nature. Isaac Newton's classic treatise, which is a landmark in the history of modern science, was entitled *Mathematical Principles of Natural Philosophy*. The word philosophy is derived from two Greek words: *philos*: love, and *sophia*: knowledge or wisdom. The term natural philosophy is more descriptive than science since love of knowledge is as important a factor in the scientific quest as knowledge itself.

During the eighteenth century, some writers began to use the word science in the sense of any systematic field of study. But it was not until the nineteenth century, after the establishment of the British Association for the Advancement of Science in 1831 that the word gradually came into more general use in its modern connotation. Not long after this, the British philosopher of science William Whewell noted that the language lacked a word for the practitioner of science, and he introduced the word *scientist* to describe such a person. The classification of science into various branches, and the need for specialization, also began in a more systematic way only during the nineteenth century.

Some Definitions of Science

Science is a well-recognized field of human endeavor. Generally speaking, there is no explicit disagreement among practicing scientists as to what constitutes science. Yet, there is no satisfactory definition of the term; that is, one that will be acceptable to all scientists. Many writers, both scientists and philosophers, have given their own descriptive definitions, most of them referring to the knowledge aspect of science.

Thus, according to Herbert Spencer, "Science is organized knowledge." Random bits of information do not constitute science; science is rather an organized totality of it pertaining to a particular field of enquiry. But then a telephone directory is also organized knowledge (about people's phone numbers), and so is a library catalogue. Thomas Huxley stressed the depth rather than the quality of this knowledge when he said that "science is nothing but trained and

organized common sense, differing from the latter only as a veteran may differ from a raw recruit." This is no longer applicable to all branches of science. The need for systematic training in the acquisition, evaluation, and organization of knowledge is stressed in this definition. But then, fields like neuroscience, condensed matter physics, and quantum mechanics are far more than organized common sense. That there is more to science than mere experience, however detailed, is brought out in G N Lewis' definition which says that "science is the systematic classification of experience." But then, not every systematic classification of experience is of interest to science: a detailed account of one's vacation in half a dozen different countries may not qualify as science. There is much more to science than classification of information.

These definitions also give the impression that science is a static storehouse of carefully arranged pieces of information, although Huxley's definition also refers to the role of the human mind in the matter. This human aspect is emphasized in G de Santillana's view of science as being "nothing but developed perception, interpreted intent, common sense rounded out and minutely articulated." Clear and applicable as this description is for science, art could also be regarded as "developed perception and interpreted intent." Some regard religious experience also as such.

Finally, the role of investigations, the formulation of hypotheses, and the statement of laws in science are all taken into account in the following definition as given in a standard dictionary: "Science is any department of knowledge in which the results of investigation have been logically arranged and systematized in the form of hypotheses and general laws subject to verification."

The Scientific Spirit

There is another view which regards science as more than just knowledge and information. It goes beyond the notion that science is essentially the sophisticated exercise of the human faculty to receive knowledge in a refined way. In this view, science is a human activity that arises from innate urges. It is conveyed by George Sarton's rhetorical question: "May we not say that whenever the attempt to solve a problem is made methodically, according to a predetermined order or plan, we are witnessing the very growth of science?"

It is important to understand what may be called the scientific spirit, which can be described as that characteristic in human beings which tries to understand, interpret, and explain the world of experience. The scientific spirit is there in all normal human beings, so it has found expression in all cultures and civilizations. It is universal. It arises from the wonderment which everyone experiences at the variety and splendor of the phenomenal world. We are awed by the vastness of the star-studded sky. We are moved by the majesty of mountains and rivers. But

equally, we are provoked to search for causes and find reasons for what we observe. We wish to know more about the world than we do. We want to figure out when the world came to be, how and why. Already in childhood we display such curiosity. All these are expressions of the scientific spirit.

Ancient thinkers were very aware of this propensity of the human mind to find out about things. The Vedic sage poets reflected on this. The Upanishadic thinkers answered those questions in a mystical framework. One may read about the fruits and dangers of such inquiries in the story of Adam and Eve. It was curiosity that prompted Eve to persuade Adam to take a bite of the apple. This is symbolic of the pursuit of knowledge. Curiosity may have plunged humanity into eternal sin and suffering, it may even kill the cat, but it is at the root of all science. Psychologists may interpret why the human being is a curious animal, evolutionary biologists may explain it, some religious thinkers may even ask us to curb it, but it is there whether we like it or not, and it is what provokes the enterprise called science.

Dynamic View of Science

Equally important in any appraisal of science are the methods by which results are arrived at. When we are told that the Sun is 93 million miles away from the Earth, we tend to imagine that we are learning science; on the other hand, when we are informed that King Ashoka reigned in the third century B.C.E., and sent Buddhist missionaries beyond India, that sounds like history. Yet, there is essentially no difference between the two statements in terms of understanding either of them. Both are bits of information, and neither of them is science by itself. On the other hand, consider the questions: How does one go about determining the distance from the Sun or establishing when Ashoka lived or what he did? On what basis can we be sure that these statements are correct or reliable? Answers to such questions are what constitute science. Exploration of the methods by which we fix the age of the Earth, we analyze the historicity of the reported miracles of saints, the reliability of a poet hearing cosmic vibrations or a prophet receiving messages from an angel: these are instances of science in action, even if the topics may not always seem to be science as the word is commonly understood.

Human beings interact with the world around in different ways and at different levels: with feelings and emotions, with intuition and action, as also with the mind. We are sensual and emotional beings, sentimental, rational, and spiritual too. The poet and the philosopher, the artist and the mystic, the activist and the religiously inspired person, the lover and the rationalist, all respond and react to the world of experience. There is a little of each of these in all of us. We can be scientist and philosopher, poet and mystic, lover and gourmand, at different times. Some of the things we do as individuals. Some we do collectively.

Science is one particular mode by which we react to the world of experience. It is humanity's collective effort to grasp the universe of phenomena, primarily with the mind. That is to say, in science one tries to comprehend the world in terms of reasons, relations, and reference systems. Science is a search for order in the physical world, for consistency and coherence in our interpretations of the world. In this sense, science has existed, and exists, in all cultures and societies. Ever since the dawn of consciousness human beings have tried to understand and interpret the experienced world. So we have had science in ancient China and India, Babylonia and Egypt, Greece, Rome and in other regions of the world also.

But the ways by which human beings have been trying to understand the complexity of the world have not been the same at all times and in all places. So there have been regional sciences throughout history. Rich and colorful in their different ways, insightful and of universal relevance in some of their discoveries, the sciences of the ancient world were in many instances culture-bound and tradition-related. But the scientific revolution of the sixteenth and seventeenth centuries ushered in a new kind of science which was based on significantly new methods. Though this science itself grew from earlier roots, drawing from the groundwork that had been developed in the ancient sciences, the framework, outlook, and results that constitute modern science are based on ways very different from the older sciences. Modern science is still mistakenly called *Western science* by many. It is as Western as the concept of the zero is Indian – in the geography of the origin, and not in the content of the insight.

Respect for the Word *Scientific,* and Some Puzzling Claims

Notwithstanding all the definitions, the word science is also misused in a variety of contexts. Not just in advertisements to sell products, but even in ordinary conversations, one uses the word *scientific* to give respectability to arguments, but little more. Often people use it to mean that a contention is fairly reasonable. Yet use the word whenever they appropriate a discovery or a technical term from science to put forward a case. Attempts to revive ancient theories about the nature of consciousness or of the origin of the universe illustrate this. Another instance where the word *scientific* is misused is in astrological predictions based on the positions of Neptune or Uranus, planets which were unknown to the originators of ancient astrology. Generally, people feel that a thesis takes on additional weight and credibility if it is described as scientific. Just as, no matter what one thinks or does, one dare not say one is a racist or woman-oppressor in the modern world, so too, no one would proudly proclaim that he or she is unscientific.

Numerous popular books elaborate on the thesis that scientific truths may also be found in the sacred book(s) of the author's affiliation, and that some important doctrines of a particular

religion may be seen in the framework of current science. Thus, depending on the author one reads, one will find that important principles from quantum physics, cosmology, even thermodynamics, can be detected in the Bible, in the Upanishads or in the Qu'ran, though couched in a different language. Such books don't explain why all these insights of modern science remained hidden and unexploited for so many centuries, and why they began to emerge for the benefit of the world only after the sixteenth century, and that too, only to some people who lived far away from the original sources. There is something puzzling in the contention that the results of modern science are in ancient texts, and that it is only a matter of interpretation to unveil the findings of modern science in works that are venerated in worship centers.

A Descriptive Definition of Science

One modern philosopher of science defined science as what scientists do. This is not just a witty quip. In fact, it reflects the variety of activities in which working scientists are engaged. Scientists collect data, do experiments, observe phenomena, hypothesize, theorize, apply mathematics, devise and use instruments, present their ideas and results to fellow scientists for comments and criticisms, comment on and criticize their colleagues' works, write papers, give seminars, and do such things. All these are what scientists do.

Many arguments and controversies arise between scientists and non-scientists, especially philosophers, sociologists, and theologians, as to the nature and validity of science. Often they reflect a misunderstanding on the part of those who have never done science except in school or college, perhaps, in a course or two. Generally, though not always, harsh critics of science have seldom themselves practiced a hard-science: done experiments or calculations, written papers or propounded theories. Without such experiences, it is difficult to fully grasp what scientists actually do to achieve their goals. Given all this, it will be useful to have the following descriptive definition of science:

Science is a collective intellectual effort by the human mind to grasp all aspects of the world of perceived reality in terms of conceptual categories, and whenever possible, with the aid of mathematical analysis and ingenious instruments.

This definition describes some of the important features of what we call science. To understand its full import, let us look a little closer into what each of the terms in it signifies.

Collective: There is no branch of science that is the work of a single individual. Science invariably involves the participation of a community of workers in any given field. This is an important distinction between science and art. Most often a work of art, like poetry, painting, fiction, or a musical piece, is the creation of a single individual. The artist may be influenced by

other artists, but what he or she brings forth is a personal work. A play by Kalidasa is essentially Kalidasa's as a *kirtanam* by Thyagaraja is Thyagaraja's alone, whether or not they admired or rejected other creators in the field. On the other hand, no scientist can hope to accomplish anything of significance if he or she ignores or is unaware of what other scientists in the field have done before. Intellectual loners have little chance of doing anything important in science, much less gain recognition for their work. It has been rightly said that every scientist has to stand on the shoulders of giants in order to see a little further, and make any meaningful progress.

Indeed, this is one of the major differences between ancient science and modern. In the ancient world, every thinker gave a persuasive theory as to how particular phenomena and the world at large arose, based largely on how each felt about the matter. So arose the theories of Plato and of Aristotle, of Brahmagupta and of Alhazen. In the world of modern science, however, intelligent or individual speculation carries but little weight, unless it arises from an intimate understanding of what other investigators have had to say on the subject, and unless it is presented with references to current literature in the field.

Science is like an edifice that is built little by little by the contributors and collaboration of well-informed people. Individuals have founded religions and philosophies. Their disciples and later generations usually repeat, interpret, and justify the sayings of the Masters. Admiring followers propagate the wisdom of the Great Ones for all to accept and applaud. In science, however, even if an individual makes an initial discovery or articulates a new insight, others pounce upon it to improve upon, explore further, correct or reject if necessary, the thoughts and insights of the pioneering scientist. Sometimes, even a student may upset the accepted theory of the teacher.

***Intellectual*:** The term is used here to refer to certain important mental capacities. The human mind is capable of many things. These include the capacity for:

(a) reasoning, which involves a disciplined mode of thinking in conformity with the fundamental rules of logic;

(b) conceptualization, which involves the development of abstract concepts to describe and comprehend our experiences;

(c) analysis, which is the capacity to take apart and explore the significance and tenability of the concepts;

(d) careful criticism which is the capacity to detect logical flaws in thinking;

(e) the formulation of reference systems, which puts a body of knowledge in proper perspective.

All these faculties play a role in the practice of science. Here it must be noted that there is much more to the human experience than intellectual interaction with the world around us. Thus there are the spiritual, aesthetic, and emotional dimensions which are no less significant for a full life. All these enter into science too, even as there are intellectual components in religion, art and literature too. But in each realm of activity, one aspect dominates more than the others. In science, it is the intellect that dominates.

***Human mind*:** The mind is among the many functions and manifestations of the human brain. Science involves the articulation by the human mind of the experiences which are part of conscious existence. In particular, science tries to understand and explain these experiences. It is important to recognize in this context that this makes science an essentially human enterprise. This fact could raise some philosophical issues. Thus, for example, if the human mind plays a crucial role in science, to what extent can scientific knowledge be regarded as entirely *objective*, that is to say, as knowledge about how the external world is, independent of the human mind? Even if there is such a thing as an external world, is not science merely a reflection of it in the human mind? These are valid questions which we may explore in another essay.

***Grasp*:** The word is used in the sense of taking hold of.

All Aspects : As mentioned earlier, the goal of science is to take into account and understand in its terminology and conceptual framework every item of human experience. Philosophers have debated the question as to whether or how far such a goal is realizable. After all, the complexity of the universe is staggering. As the Tamil poet Auvaiyar pithily observed, "What has been learned is a handful, the yet-to-be-learned as vast as the world." Every time we probe a little more, a little deeper, the world becomes still more intriguing. This is especially the case with respect to the life sciences, and even more so in the context of the human brain and its multifaceted manifestations.

Can science ever completely unscramble the mechanisms by which thought and ideas and values, joys and sorrows and humor emerge? Perhaps the grand goal of science, like the ideals of human society, may never be reached *in toto*. However, not many working scientists normally doubt that science will be able to explain little by little every feature of the phenomenal world. We may go on and on for a very long time with the job of science never fully done. But it has also been suggested that science may be able to account for everything, including thought and emotions and love and the apprehension of truth and beauty, only if it modifies some of its current fundamental assumptions. Some of the efforts in the newly emerging field of consciousness physics are treading along this path.

World of Perceived Reality: We come to know about the world primarily through our doors of perception. There are many features of the world that we do not ordinarily recognize. Such, for instance, are certain gases in the atmosphere, micro-organisms, and microwaves. However, all these can be perceived indirectly, through instruments, inference, and ingenuity. Beyond all this and conceptually, one may picture levels of reality which are beyond human perception. One may also imagine a universe beyond perceived reality with angels and spirits, *gandharvas* and *apsaras* that cannot be perceived in any way. Science can say or know nothing about these. If such exist, they are beyond the scope and consideration of science. Science can and does deal only with the dimension of reality which is, or which can potentially be, perceived, either directly or indirectly, through the normal human channels of perception. In other words, everything that science deals with or talks about is related in some way or another to some aspect or another of what normal human beings can perceive in one way or another. This is the reason why ghosts and goblins, whether they exist or not, have no interest for science. It is sometimes argued that scientists who do not take supernatural entities seriously have a closed mind. This is not a fair assessment of their skepticism. If and when such elements are brought within the perceptual realm, the world of science will begin to take more than an active interest in them. Until then, science cannot be expected to take them seriously.

***Conceptual Categories*:** The scientific enterprise rests on carefully constructed concepts and clearly defined terms. For the success and advancement of science, concepts are essential. Concepts are images that the mind creates, in terms of which one can develop reasoned discourse. Some concepts can be visualized, and some not. Some may not correspond to directly observed or observable entities, or even to aspects of perceived reality. Thus, for example, one can visualize concepts like speed, force and momentum, even entropy and energy. However, one cannot visualize concepts like the Hamiltonian, isotopic spin, or wave function which play important roles in physics. One may raise the question of their existence in the physical world. As far is science is concerned, though these cannot be perceived as such, they can be related one way or another to some aspect(s) or other of perceived reality. They are therefore very relevant to science.

On the other hand, concepts like life-force, entelechy, élan vital, supermind, primordial egg, Zeitgeist, etc. may be fascinating in picturing certain features of the living or the natural world, but they are not connected with any measurable features of the world. It is important to distinguish between poetic imagery and philosophical constructs on the one hand, and scientific concepts on the other.

Mathematical Analysis: A good deal of successful science involves describing observed facts in quantitative terms; and it calls for (often abstract) mathematical analysis and reasoning. It

turns out that when we describe things or phenomena in quantitative terms, we arrive at a deeper understanding and greater manipulative power over them. Moreover, we find that many phenomena in nature are governed by mathematically precise laws. As Galileo expressed early in the emergence of modern science, the laws of nature are written in the language of mathematics. In some instances, not just for a deeper understanding, but for plain recognition of certain features of the physical world, mathematical language becomes indispensable. Thus, not only the particular geometrical shapes of planetary orbits, but much of our knowledge of the microcosm (atomic and subatomic physics) would be impossible without the use of sophisticated mathematics. Indeed, modern science would not have arisen without the mathematization of the world.

***Ingenious Instruments*:** The human faculties of perception are considerably enhanced and extended by a variety of devices, from the very simple to the very complex. There are countless instruments which serve science. Our faculties of perception are limited in two ways: By their sensitivity, and by the input threshold. Very faint light cannot be seen, very faint sound cannot be heard. To correct for these, we have amplifying instruments. The threshold limitation refers to the fact that the human eye is not sensitive to electromagnetic waves with frequencies outside of the visible spectrum. Likewise, the human ear cannot hear ultrasonic or infrasonic pressure waves. These thresholds have been extended with instruments.

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