The Scientific Enterprise

3. Assumptions, Problems, and Goals in the Modern Scientific Framework

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Rational Intelligibility of the World

The first assumption of science is that the human mind has the capacity to unravel and comprehend the laws of the physical world. It is true that the universe is extraordinarily complex and unimaginably infinite in its scope and variety, but science contends that it is not impossible for our finite minds to grasp all the variety and complexity. Through mathematics we have been able to understand many subtle features of the physical world, prompting Eugene Wigner to coin the phrase, as title of an article (1960),"the unreasonable effectiveness of mathematics." But there are also entities and phenomena which we do not yet fully understand: such as the origin of consciousness, the generation of thoughts, the cause of the initial symmetry-breaking that led to the Big Bang, etc. Then there are matters relating to human fortunes, ultimate human destiny, etc. Science (i.e., every die-hard scientist) believes that these and everything present in the phenomenal world will someday be resolved through the scientific quest. The human mind does not yet know all the secrets of the universe, but eventually it will. This *is* a conviction that enables science to continue its quest tirelessly. This does not mean that scientists cannot be humble. As Albert Einstein wisely said, "*My feeling is religious insofar as I am imbued with the consciousness of the insufficiency of the human mind to understand more deeply the harmony of the Universe which we try to formulate as laws of nature.*"

Kinds of Problems

Scientists are engaged in solving different kinds of problems, some of which we consider here. Most problems in science are related to *explaining specific phenomena*. First one observes some aspect of the world. Careful observation often leads to a preliminary understanding of the phenomenon . The challenge now is to explain what has been observed. For example, suppose an astronomer, while scanning the heavens, finds a new object in the sky: it could be a comet or a star or a supernova. One will have to explain what it is and how it suddenly came to be.

Sometimes, a theory in science will not only explain the newly-recognized phenomenon, but also affirm the existence of a related one or suggest some aspect of the world which has not yet

* Part 1. Science: Some Definitions and Views, *Resonance*, Vol.13, No.6, pp.596–605, 2008
Part 2. Ancient Science and Worldviews, *Resonance*, Vol.13, No.8, pp.778–792, 2008

been considered or confirmed. In such situations, scientists will try to do the appropriate experiments to *put into evidence what is theoretically predicted*. For example: James Clerk Maxwell's theory of electromagnetism (1864–73) predicted the existence of electromagnetic waves. These were put into evidence experimentally by Heinrich Hertz in 1888. (It may be noted in passing that the artificial production of electromagnetic waves was perhaps the most important experiment in the history of science in terms of the impact on human civilization.) In 1962, a very successful theory (SU(3) and the related Eight-fold way of Murray Gell-Mann) in high energy physics predicted the existence of a hitherto unknown fundamental particle, which was named W^{-} (omega-minus). Two years later it was experimentally discovered at the Brookhaven National Laboratory. Likewise, in 1962 from theoretical considerations George Sudarshan *et al*. postulated the existence of faster-than-light particles (later named *tachyons* by Gerald Feinberg). Experimental physicists are still trying to establish their existence.

In some instances, one may have collected a mass of experimental data pertaining to a phenomenon, but the data may be cluttered. Then it becomes a challenge for the scientist to *seek some discernible order in the jumbled data that has been accumulated*. For example, by the close of the 19th century, spectroscopists had carefully measured the wavelengths of radiations coming from a hot hydrogen source. The wavelengths of the visible lines are: 410 nm, 434 nm, 486 nm, and 656 nm. The challenge was to discover any possible relationship between these wavelengths. In 1885 Johann Balmer detected a simple formula from which these numbers could be derived. This led eventually to the discovery of atomic structure. Thus, detecting pattern(s) in a mass of accumulated data is another type of problem.

Sometimes, in the midst of a well-ordered pattern, there may appear something that is not expected in the accepted framework. For example, it was found that in the case of the emission of photo-electrons from metals, their energy did not increase by increasing the intensity of the radiation. This was contrary to what one would expect from the classical electromagnetic theory. This led eventually to Einstein's theory of the photoelectric effect which considered the incident radiation in terms of photons. Similarly, the doublet in the spectrum of alkali metals led to the theory and discovery of the electron-spin. Note that in all these instances where one tries to *account for the unexpected*, careful observation led to the uncovering of thus far unrecognized phenomena.

A theory may explain every aspect of a certain phenomenon, and yet observations might reveal that there is some feature of it that goes contrary to the theory. One will then have to *account for the deviation from the normal*. For example, in 1781 the planet Uranus was discovered telescopically by William Herschel. It was soon found that its orbit was not exactly a perfect ellipse as one would have expected. This was an anomaly, and John Couch Adams, a young graduate tried to explain this in terms of an as yet undetected planet. These ideas and calculations did not receive any attention from the astronomer Royal Broge Biddell Airy. In the meanwhile the Frenchman Urbain Leverrier sent his results to the astronomer Johann Gottfried Galle in Berlin who succeeded in locating the planet we now call Neptune.

The Goal and Limitations of Science

Science tries to understand and explain every aspect of the perceived physical universe by adopting the scientific methodology. One may describe this as the bold optimism or the haughtiness of science. Those who look upon this as unrealistic point out that this goal cannot be reached, for at least two reasons: First, the universe is infinite in its complexity. As the poet John Dryden put it, "But how can the finite grasp infinity?" Also, they say, science cannot answer such questions as: What is the purpose of life? Does the universe have a goal? Who created the world? What is good behavior? These are interesting and important questions, but they do not refer to observed phenomena. Unfortunately, no other system can answer these questions either.

Secondly, as noted earlier, one may say that not every aspect of the universe can be understood within the framework of the scientific methodology. It has been argued that some matters like love, values like honesty, and ethical principles like compassion and kindness, will never be fully amenable to scientific analysis. Many scientists grant that the goal of complete explanation of everything will not be achieved from the efforts of a few, or even of a great number of dedicated scientists in the near future, but they share the hope that the scientific quest will continue for as long as the human species exists, and that eventually it will unravel the roots of even deeply felt experiences, values and the ethical principles.

The ultimate goal of science is to *explain in coherent, consistent, and causal terms* every aspect of the perceived world. This does not mean that the world becomes less important or less interesting when one recognizes them through other modes. Thus love, truth, and compassion are no less significant when they are not explained scientifically, and not any more if and when they are. Whether it is the magnificent sunset or the colorful rainbow, a fragrant flower or a majestic mountain, glorious music or interpersonal love, one can experience and enjoy these without explaining them.

What Science is Not

Contrary to general impressions, the aim of science is *not* to discover useful results which may be applied for practical purposes, although individual scientists may be engaged in such projects. Nor is it the goal of science to make life more comfortable for humankind, to find cures for diseases, or to develop weapons of warfare, although individual scientists may be engaged in such activities. It is possible for a society to be quite successful in exploiting the practical applications of science without making any scientific breakthrough. In other words, a country can be productive in industry and successful in technology without any of its members being engaged in serious scientific research. Technology can thrive without science in a world where technological know-how can be shared, openly or otherwise. Electrical power generation, pharmaceutical industry, and nuclear weapons production can all occur even where there are no centers for pure scientific research. Science tries to understand, offer explanations, correlate observed phenomena in terms of well-defined concepts and frameworks, and discover as yet unknown phenomena. Scientific research is necessary for the advancement of knowledge about the world, and not for the application of already discovered knowledge.

Reality and Realism

Another important assumption of science relates to the reality of the world. One assumes that there are external entities in the physical world whose existence does not depend on the presence of the human mind. Thus, rocks and oceans, Sun and stars, heat and light, are assumed to have been there even before the emergence of humans. Science assumes that the physical universe will continue in whatever form even after human beings no longer exist.

This belief in an external world of objects and entities independent of the human mind is generally referred to as realism. It has been subjected to considerable philosophical analysis. Some have rejected it totally, holding that the entire world is no more than the creation of the human mind, that the whole cosmic show is a consistent fabrication of complex brains. This view does not explain how the brain came to be. Working scientists do not normally engage in such speculations, leaving them to clever philosophers. It must be noted that the view of a mind-generated reality, known as pure idealism, is not without logical merit. It has been convincingly put forth by many competent philosophers, including some philosophers of science.

In the Hindu metaphysical framework, one distinguishes between the ephemeral phenomenal world, and an underlying principle that remains for ever. Here, reality is looked upon as that which remains unchanged with the passage of time, and will be there all through eternity. This is a perfectly acceptable *definition* of the Ultimate Reality. When the sage-poet Shankara declared succinctly, "*Brahma satyam, jagat mithya*" (Brahman alone is real, the phenomenal world is illusory), he made a distinction between the permanent and the transient. From this perspective, the phenomenal world is essentially a delusion. This is surely a deep insight into the nature of the physical world where all things from elementary particles and common occurrences to stars and galaxies change and pass away. According to some grand unified theories, even the proton will eventually decay via X-bosons.

However, it is important not to trivialize the transient phenomenal world. The world, like human life, may be too short to be taken seriously from a larger cosmic perspective; but it is too long not to be taken seriously in the context of human affairs. Exploring ephemeral reality and trying to understand it are the goals of the scientific enterprise. Science is one of the loftiest expressions of the human spirit in that it has revealed to human understanding a myriad marvelous features of the changing world. The understanding has expanded the human mind immensely. The knowledge gained from science has also enabled vast numbers of people all over the world to live more fully, more healthily, and more comfortably.

Scientific realism is not naive realism. According to naive realism, the things we see and feel around us are exactly as they appear to us. Unreflecting realism makes us believe that things are intrinsically red or blue, rough or smooth, round or elliptical, etc. But our senses can sometimes deceive. Illusions can be created in our minds as well as in our perceptions. Shankara reminded us of how the un-examining mind can mistake a rope for a snake in the dark. The (apparent) rising and setting of the sun is another simple example of this possibility.

The working scientist recognizes the existence of a passing world, and is well aware that the impressions we get of that world arise from our sense perceptions. Scientific investigation tries to sort out the perceptual factors from the objective, and tries to express the relationships and patterns in the phenomenal world in terms of ideas that are generated in the human mind. The scientific interpretation of the world includes a whole array of conceptual elements, from kinetic energy and momentum, to electric potential and wave function.

Sense-experience is an inevitable instrument for all knowledge and understanding. In other words, even if we grant the existence of an external objective world independent of the human mind, what we actually recognize as reality is the reaction of our nervous system (through our channels of perception) to the stimuli emanating from that world. The most we can claim to know and try to explain is what results from the interaction between an external world and our sense perceptions. Understanding the perceived world, stripped of all illusion-generating factors, is a major concern of science. The enhancement of our perceptions and the removal of misleading intrusions are accomplished through instruments and carefully devised experiments. That is why experiments are the ultimate source of much valid knowledge.

Empiricism implies that the only world we can know is the one resulting from sense perceptions, that there is nothing beyond sense perceptions. In other words, in this framework, the reality we study is simply those sense perceptions themselves. Thus, we cannot even be sure that there is an external objective world. This line of reasoning may cast doubt on realism.

On Physical Laws, Causality, and Locality

The world we perceive is not static. It consists of processes that operate incessantly in the universe. Science assumes that these processes are governed by well-determined principles and laws. In other words, events and changes occur in the physical world, not chaotically and at random, but in orderly ways. Even apparently sudden outbursts, such as the stupendous explosion of a supernova, the violent surge of fumes from a volcano, or the ominous upsurge of a tsunami, are the outcomes of the endless operation of fundamental physical–chemical laws. Thus, another assumption of science is the existence of inexorable laws and principles.

One of the universal principles implicit in science is that of causality. Every occurrence in the world is caused by something or other. Nothing happens by itself, uncaused and unprovoked. The myriad phenomena we see around us are the results of a myriad others which themselves are caused by still others. The countless facets of the world are all intertwined by complicated causal chains. The notion of causality has given rise to many philosophical discussions and disagreements, most of all to attempts to seek the precise ways in which a cause is linked to its effect. Since it is practically impossible to ascribe any event to a single cause, the problem becomes all the more difficult. It is easy to say that the cause of a ball's fall is gravity, but would it have fallen if there had been a table top to support it? Thus, is not the absence of a table equally a cause of its fall? Again, would it have fallen if it had not been lifted up from the ground to begin with? And what about its specific gravity with respect to the medium in which it is? If the ball were filled with helium, for example, would it have fallen down in the Earth's atmosphere? The assumption in science is that while an event may – and often does – have more than one cause, it cannot be without *any* cause.

Associated with the principle of causality is the idea of *locality*. According to this, it takes a finite interval of time for a cause in one region to produce an effect in another. In other words, it is impossible for something to occur in one part of the universe and for its effect to be produced simultaneously in some other remote part. Thus, while it is possible to do something in a control room on Earth and affect a spacecraft moving in the vicinity of, say, Jupiter, it will take some time for the effect to be transmitted there. Or again, when we see a distant star, it is the effect of some atomic transition or nuclear reaction that took place a few years or even centuries ago. In other words, though effects may be produced millions and trillions of miles away, these will always require some time to act. This is one of the cornerstones of scientific thought. More exactly, since (in the current framework of physics) nothing can travel faster than light, if two points are separated by a distance x, the minimum amount of time t required for the transmission of an effect will be given by $t = x/c$, where c is the speed of light. Some doubt has been cast on this tenet of modern physics as a result of certain quantum mechanical considerations and experiments.

Though one speaks of cause and effect, these are extremely complex to track down, both in theory and in actuality. The world results from an enormously complex web of causal connections whose congruence can have enormous possibilities.

On the Physical-Law-Basis of the World and the Hypercomplex Level

The laws and principles governing the physical world are space-time invariant. That is to say, the same laws hold here and now as they do in every center and corner of the universe at large. According to current cosmological theories, the laws of physics came into effect only after the first Big Bang which brought forth the universe. In fact, in the first inconceivably short instant after that event, some aspects of physical laws became unrecognizably different. In particular, the so-called fundamental forces began to manifest themselves as such. Their effectiveness has been there from the earliest moments of cosmic birth. This is one of the basic assumptions of science: that these laws have always characterized the physical universe.

This is only an assumption because it need not necessarily be the case. There is no proof for the statement that ten billion years ago the laws of physics were exactly the same as they are today, or that these very same laws operate in galaxies millions of light years away. However, if the laws of the physical universe changed from time to time or from place to place, there would be universal chaos, and science would be impossible.

We may also imagine that events occur in the physical universe, as they seem to do in human societies, by the will and whim of a supernatural source. Such a possibility seemed especially acceptable in earlier times in difficult-to-track events like lightning and thunder and earthquakes. However, in the world of modern science one assumes that physical laws and principles operate inexorably, blindly as it were, not at the direction of a super-mind or a willful cosmic puppeteer, but because they are there.

Now there are aspects of the experienced (human) world that do not seem to result from well-defined laws. Such are events in history, the behavior of people, the emergence of thoughts, experiences in dreams, and the course of biological evolution. These constitute what may be called the *hypercomplex* level of reality. The course of an individual's life or of the history of a nation can never be predicted with certainty or even probabilistically on the basis of physical laws. Mutations may occur as a result of random cosmic rays impinging on cells. The fusion of a particular sperm with an ovum resulting in the birth of a human being is utterly unpredictable. A different sperm could have produced an entirely different human being with considerably greater impact or no impact at all on humanity. A chance encounter between two persons in a train can alter their entire lives. We constantly live at the hypercomplex level of reality.

And yet, as per current science, a world whose elements behave in utterly lawless ways is impossible. This essential element in the scientific framework, namely that everything can be reduced to physical laws and principles, has recently been described by Stuart Kauffman as the *Galilean spell* (in his book *Reinventing the Sacred* (2008)). All of classical science – and especially of classical physics – rests on the Galilean spell. A world without laws and principles – if it were to exist – can at best be described, but never accounted for. Explanation implies the existence of rules, order, patterns. Explanation is ultimately description in terms of underlying laws and principles to account for what is observed. Without the assumption that there are underlying laws in the observed world, there cannot be any science.

This means that we must distinguish between aspects of the world that can be systematically and cogently explained on the basis of physical laws and principles, and those that cannot be so done. It is this latter possibility that gives rise to creativity and new elements in the universe.

Purposelessness of the World

Another assumption of science is that the universe as a whole and the laws governing it have nothing to do with the welfare or otherwise of humankind. What this means is that according to the worldview of science, the laws of nature did not emerge with humanity or anything else as a goal. Indeed, there is no goal, no end in aim for the universe. Like a mammoth machine wound up and left to itself, the universe continues on and on. Its constituents evolve in accordance with the laws to which they are subject. While it is true that it is because of these laws that living organisms in general and human beings in particular have emerged like planets and stars, all these are merely some of the countless consequences of those laws. Sometimes we benefit from them, at other times we suffer. But the universe is in no way affected by whether we gain or lose. The phenomenal world is looked upon by science as being neither good nor bad to us, merely indifferent to the human predicament.

Physicist Steven Weinberg expressed this idea explicitly in his book *The First Three Minutes* (1977,1993) where he said, "The more the universe appears comprehensible, the more it also appears pointless." This may make some people feel quite uncomfortable. In the world around us there are innumerable wonderful things and occurrences causing joy and laughter. The chirping of birds and the setting of the Sun, the fragrance of flowers and the babbling of babies, all these create delightful experiences. The human spirit is itself capable of so many remarkable feats that it is hard to believe that this vast and calculable universe came about for no purpose but to continue on and on, coldly and callously, for eons upon eons of utterly meaningless existence.

In this context, one needs to be clear that Weinberg's statement is valid only in the sense that working physicists who observe and theorize about the world have not been able to detect any purpose. It is unfortunately a fact that the more we understand the complexities and the expanse in space and time of our universe, and the more we unravel its silent behavior and underlying principles, the less it seems to be the case that there is any ultimate purpose to it all. In other words, the lack of purpose for the world at large is a *conclusion* from much of what have been able to observe and understand by the adoption of the scientific methodology for exploring the universe, and not a formal *à priori* doctrine or assumption.

Here we may take note of the fact that, in the last quarter of the twentieth century, some interesting and intriguing features of the physical world were recognized which have been interpreted in terms of a purposeful universe. This is the so-called *anthropic principle* which will be discussed later in this series.

Concluding Thoughts

The goals and assumptions of science may seem arbitrary, but they are implicitly accepted by the scientific community. Individual scientists may reject some of these in their personal capacities, but they cannot afford to do so as working scientists. Some scientists have tried to further the cause of science by suspending allegiance to some of these assumptions, but thus far no one has been spectacularly successful in this.

An individual or a group may strive towards achieving any other set of goals, and work on the basis of other assumptions. The assumptions of science are in a sense *à posteriori*: they have become entrenched in the minds of scientists as a result of the successes flowing from them. Non-scientists sometimes insist that scientific knowledge is not absolute, because it is based on these assumptions which may not be necessarily true. To this the scientific enterprise might reply that others are welcome to acquire knowledge on the basis of other assumptions and methodologies, and if they find such knowledge satisfying let it be so. But it would be unreasonable to demand that knowledge acquired by adopting a different methodology or a different set of assumptions should be accepted as scientific. Science is a serious game, played according to certain internationally accepted, but not always explicitly articulated, rules. If one wishes to play the game, one must adhere to the rules.

Some of these assumptions *may be* wrong. For example, it may well be that the world around is purely illusory. If so, science is interested in that illusory world. Or again, one may say that events can or do occur in the world without any cause. Indeed, we know that in interpreting certain microcosmic phenomena such as radioactivity we need to refine our common sense notions of cause and effect. Thus the assumptions of science are not rigid and inflexible.

The knowledge and understanding about the world gained on the basis of the scientific framework have turned out to be rich and extensive, interesting, insightful, unsurpassed, and culture-independent. Unless there are compelling reasons to discard the fundamental assumptions of science, the scientific enterprise is not likely to replace or abandon them.

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