

# Nature of Science\*

The Evolutional, Hierarchical, and Debatable

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Since time immemorial, science has been evolving, playing an immense role from being a philosophy to a discipline and career. Its nature and categorization into many dimensions render it unique amongst all disciplines. Though the tenets, philosophy, and scientific methods of searching for the truth of the physical world make science stand apart within its realm, it encounters heaps of debates. The article focuses on the nature of science while navigating through its evolutionary journey until the present, and the way it emerged as a versatile enterprise holding hierarchical and diagonal relationships among its distinctions. Capturing the veiled philosophical and psychological realities in an exploratory fashion, the article thus tries to bring out the real nature of science concealed within the debates of science.

## Introduction

Worldwide, scientific enterprise has managed to build its image of being objective, rational, and devoid of prejudice. Though many definitions and debates hovering around science have thrown light over its nature, questions such as ‘what exactly is science?’, ‘what is good science?’, and ‘what distinguishes science from other areas of knowledge?’ have been a constant subject of inquiry among the philosophers, scientists, and other stakeholders. Does the characteristics of science as displayed to the world have consensus with its real nature or the way it operates? Since its conception as ‘science’, there have been debates about its knowledge domain, way of searching the truth about the physical world and the ‘correct’ scientific method that scientists should follow. The



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## Keywords

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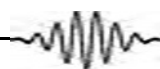
The definition of science itself has two broad views among the fraternity of science—the ‘static’ and the ‘dynamic’. It cannot be denied that within science, there are many distinctions, displaying its hierarchical nature. The hierarchical nature inbuilt in science infuse a bias while positioning the branches of sciences and related careers as opposed to its worldwide notion of being objective and unbiased.

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Amongst all, one of the most commonly stated objectives for science education is the attainment of an understanding of the nature of science as mentioned by Kimball [1]. To examine the nature of science, and the underlying debates in the realm of science, the article is divided into three sections. The first section focuses on the nature of science as evolutionary while tracking its journey from past to present. The second section highlights the hierarchical nature of science, wherein careers associated with science are ranked differently in society. The third section elaborates upon its nature of being debatable among scientists and other stakeholders, as the diverse areas which science encompasses fall under the scope of debates holding the binary positions. The individuality of these areas contributes to the versatile nature of science. Lastly, the conclusion attempts to reiterate the focus of the article by revisiting the thrust of the discussion, i.e., to understand and analyze the character of science as evolutionary, debatable, and hierarchical.

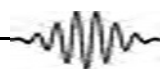
### Science as Evolutional

In the words of Clough and Olson [2], “the phrase ‘The Nature of Science’ (NOS), is often used by science educators to refer to issues such as what science is, how it works, the epistemological and ontological foundations of science, how scientists function as a social group, and how society influences and reacts to scientific endeavors” (p.143). To understand the nature of science in contemporary times, it is required to look at some of the ma-



rior perceptions of science historically. Science is derived from the Latin word, *scientia*, which means ‘knowledge’ [3, 4]. From foundations based upon intuition and logic to Kuhn’s naturalism based exclusively upon logic, science charted its journey from being natural philosophy to ‘the sciences’. Several methodological developments took place which revolutionized the tenets and philosophy of science. Sarukkai in his book *What is Science?*, highlights the journey of science in the Western context. According to him, the word science came into general use only after 1300 AD and was earlier understood as knowledge acquired by study and was called ‘natural philosophy’. The notion of method became attached to science later in the 18th century. According to the *New Encyclopedia Britannica* [5], till the end of the 18th century, spiritual and divine forces were considered real and mandate for any explanation. The early history of science was a combination of both religion and astronomy, wherein astronomy was regarded as the queen of science. It is believed that the notion of inquiry, reason, and rationality to the field of sciences was introduced during Greek civilization. But some historians argue that it displays a biased picture given by the Eurocentric view. Bala [6] brings to light another view of the origin of modern science and argues that the Eurocentric view displays a biased and distorted narrative of the origin of modern science. The Eurocentric view highlights the contributions of Greeks as the major factor in the origin of modern science and negates the influence of other cultures such as Chinese, Indian, and Arabs. The author raises some important questions regarding the Eurocentric history of science as it ignores the influence of Arabic optical theory and mathematical realism, or the mechanistic conception of the universe that originated in China or the Indian mathematical atomism. The author questions the scientific ability of Greeks themselves as their mathematical knowledge was not adequate, and they were also not interested in applying math to nature. Bala thus emphasizes that the Europeans could never have produced modern science with only Greeks as role models because the Greeks were nowhere near modern science themselves. It was the contribution of other cultures that allowed Europe to weave all the necessary threads

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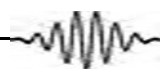


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together to create modern science. Such debates introduced a new multicultural conception of scientific development based on a new criterion of intercultural influence.

The emergence of the tradition of criticism in the history of science started when Thales, the first natural philosopher, explained all the natural phenomena in terms of water but was proved wrong. Copernicus extended the tradition of scientific criticism. Modern science arose when Copernicus brought in a scientific revolution by placing the Sun at the center of the cosmos rather than the Earth, as claimed by Aristotle before. Chalmers [7] has highlighted that many prominent changes occurred during the 20th century that saw the rise of logical positivism. Logical positivism was further criticized by Karl Popper's falsification. According to Popper, a scientist should attempt to falsify his/her hypothesis rather than trying to confirm it, as opposed to logical positivists. Another major movement called the postpositivist movement came with Kuhn's paradigm shift, which eclipsed both logical positivism and falsificationism. In the late 20th century, science moved ahead, leaving behind most of the ignorance, and with a new rational view of the world.

Based on the above discussion, it is pertinent to throw light on some of the definitions of science proposed by many scholars. According to Murray [8], science distinguishes the relevant from the irrelevant in a purely objective manner and remains uninfluenced by prejudice or bias. Murray also highlighted some aspects of scientific discipline, viz., it requires conducting careful and thorough experiments keeping in mind the possible errors and distrusting mere authority; it includes classification, evaluation and logical interpretation of the data obtained; the formulation of clear reasoning of the hypothesis from a sufficient number of results, and testing of the hypothesis by further results until it is confirmed and accepted. The *New Encyclopedia Britannica* [5] defines science as "knowledge of the world of nature". It considers science as the knowledge of natural phenomena that shows regularities when subjected to some degree of skeptical rigor and can be explained by rational causes. This points towards the scope

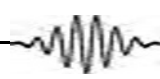


of further enhancement in the already established knowledge of natural phenomena, which can be achieved through continuous testing and rechecking of the facts in the new set up and conditions. National Academy of Sciences [9] noted that the questions that science asks are—“What exists and what happens?”, “Why does it happen?”, “How does one know?”, etc. Any new idea is initially tentative, but over time, as it survives repeated testing, it acquires the status of a fact and a piece of knowledge that is unquestioned and uncontested.

Defining science, as put by Mohapatra and Mahapatra [10], is not an easy task, as philosophers and scientists have described its nature, structure, and functions in different forms. But the scientific world perceives two broad views of science—the static and the dynamic view. Static science is a structured domain comprising interconnected sets of principles, laws, and theories bound together in a vast array of systematized information, whereas the dynamic view sees it more as an activity, what scientists do, and how they do it. As outlined by Lederman [11], science is a dynamic, on-going activity rather than a static accumulation of information that “necessarily involves human inference, imagination, and creativity”. Based on the above definitions, science can be defined as “the systematic enterprise of gathering knowledge about the universe and organizing and condensing that knowledge into testable laws and theories” [4].

Sarukkai regards science as a consistent body of epistemological beliefs that are grounded on empiricism and objectivism which points out to its characteristics of being value-free and dissociated from society and culture. But on the contrary, many methodological developments in history show science to be inconsistent, pointing towards its evolutionary nature. Bueno & Vickers’s [12] work ‘Is science inconsistent?’ is an important reference point here. The paper highlighted that recent landmarks displaying inconsistency in science include the classical theory of the electron, Bohr’s theory of the atom, and the difficulty of reconciling Einstein’s general relativity and quantum theory. It is evident that from the time of Aristotle to the present, conceptions of science

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have been in a state of continuous change and development. The paper primarily tries to view the evolutionary character of science that lies in the essence that it is inconsistent. When one looks at the studies noted above, it is obvious that the inconsistent nature of science renders it the character of being evolutionary.

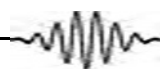
### Sciences as Hierarchical

As noted by Sarukkai [4], science is a concept that includes many disciplines. Physics, chemistry, biology, and other sciences such as earth science, wine science, and management science are related to each other as these come under the umbrella of science. There is no strict similarity among these types rather relatedness. On a broad aspect, science is basically divided into physical and biological sciences and other areas under the category of science.

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It was Auguste Comte who introduced the concept of hierarchy within the sciences almost 200 years ago. He advocated that science progresses through most prescribed stages of science developed at quite different rates. For him, astronomy, being the most general of all the sciences, develops first, followed successively by physics, chemistry, biology, and then sociology. The branches of science and careers associated with it outline the hierarchical order of arrangement of its different branches.

The existence of hierarchy has been dealt with in detail by Cole [13] who assumed that sciences are arranged in a hierarchy, with developed natural sciences like physics at the top and social sciences like sociology at the bottom. A distinction is made between two classes of knowledge based on certain parameters. Sciences at the top of the hierarchy display a higher level of consensus and more rapid rates of advancement than those at the bottom. The concept of codification plays an immense role in the distinction between hard sciences and soft social sciences. Codification means consolidation of empirical knowledge into interdependent theoretical formulation. A higher codified field such as physics stands higher in the ladder of hierarchy than the less codified fields such as sociology. In the highly codified field, knowledge

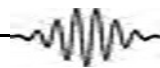


is compacted, whereas, in the less codified field, knowledge is not as compacted, and far greater experience is needed for attaining competence.

Cole explained the distinctions of the hierarchy of sciences into ‘top’ and ‘bottom’ based on six variables, viz; development of theory, quantification, cognitive consensus, predictability, rate of obsolescence, and rate of growth. It means that the sciences at the top of the hierarchy have a highly developed theory, guided by a paradigm and a high level of codification; ideas expressed in mathematical language; high level of consensus on theory, methods and significance of problem; ability to use theory to make verifiable predictions; significant cumulation of knowledge; and a high rate at which new knowledge grows. The hierarchy of science explained not only the complexity of the phenomena but also their stage of intellectual development. It has been established worldwide that physics has the highest level of paradigm development followed by chemistry, biology, economics, and psychology. It is one of the most important findings, and it is also conceived that scientists in different fields also believe that hierarchy does exist.

More recently, Schizas *et al.* [14]) emphasized the common idea shared by most of the 20th-century scientists who belonged to various scientific fields such as physical, biological, and social sciences. The positivistic idea shared was that physics, and in particular, the foundational component of physics, namely classical mechanics, should be considered as the appropriate model to judge scientific activities and understand NOS. It shows that physics is considered the most prominent among all the sciences, which should be taken as a norm for comparison. According to Schiebinger [15], physics is difficult as it “requires a high degree of abstract thinking, strong analytical skills, arduous work, and long hours”. Schiebinger, while reframing Sandra Harding, pointed out to her questioning about the prestige that physics enjoys as the model science. ‘Hardness’ as mentioned by Schiebinger [15], is thought to describe the hierarchy in sciences. “According to this paradigm, hardness is determined by the degree to which

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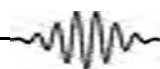


the science is thought to be built on fundamental laws that describe reality”, and in this case, physics ranks first. Schiebinger advocated the views of many physicists who think that physics should be taken as an aspirational model by all other sciences as it comprises analytical methods, the ability to reduce complex phenomena to simple principles, and follows a scale of intelligence. The inclusion of chemistry in physical sciences renders it a high rank but at par with physics. Alternatively, life sciences deal with soft, animate organisms, which do not require much abstractness. Rather it is related to direct things. This renders biology a distinct status from physics and chemistry.

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Like the streams of science, the careers associated with science also have a status attached to them, which implies that some careers enjoy high status in society. For instance, medicine is a career in science that is highly admired by the people. It is viewed as a status symbol and not just a career. Similarly, a scientist is seen with much pride than a school science teacher. There are several reasons behind this preferential treatment and immense respect to particular professions associated with sciences as opposed to others. This section also tries to deal with the difference between a scientist and a science teacher. For a clear distinction between the two, it is required to understand the definition of a scientist. To begin with, Whewell coined the term ‘scientist, [3, 4, 16]. People have a very different image of a scientist. Therefore, it has to be explored that how a scientist is perceived by society as many significant factors play a role in making the image of scientists among the people.

Many studies have explored the images of scientists among people and students. A layman’s perception of a scientist is that of an individual who stays for long hours and sometimes for several days in the laboratory. Though he might have a family who takes care of his needs and requirements, he is never disturbed or interfered by them. This means giving away all the desires and just concentrating on his work. A scientist as put by Hagstrom [17], “is a man of scientific knowledge, one who adds to what is known in the sciences by writing articles or books”. They are

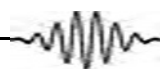




also involved in applied research, attempting to make discoveries that will lead to new industrial, medical, and agricultural products or processes. According to William [3], many scientists work ‘in the field’, collecting specimens and data. It is an integral part of their day-to-day working conditions along with the laboratory work. All scientists devote significant time to research through reading books and journals and modeling their ideas physically, mathematically, or virtually.

On the contrary, the skills of a science teacher are often assumed to be multi-disciplinary. Since science in a school-based context has its limited framework of language, procedures, equipment, and philosophy, it depends much on these limits as to what aspects need to be covered in a prescribed manner by the teacher. There is a time limit along with limited resources that a science teacher has to confine with. The aim of both the professions differ from each other as a scientist’s aim is to discover something new and then to have rights over that piece of research, publish it. On the other hand, a science teacher aims to teach the students already established knowledge by the scientists. The teacher may adopt a scientific way of teaching but his/her aim will be ultimately to make students understand the existing knowledge of science.

According to Hagstrom [17], scientists in all types of establishments are likely to combine research with other activities such as teaching, administration, and technical consultation. Whereas, the prime duty of a science teacher in a school is to engage only in teaching along with other activities that surround his/her teaching subject. William [3] stated that different knowledge sets and skills are required at a higher level, but at the school level, the science teacher has to be an all-rounder. Another point of distinction between scientists and school science teachers is that scientists tend to publish their discoveries, sometimes along with their colleagues. As mentioned by Bernard [16], the most important social incentive for scientists is to obtain recognition from colleagues for their research accomplishments. The scientists’ inclination is more towards recognition of their professional autonomy, keep-



ing it above the rewards of income.

Though the profession of teaching is underestimated as compared to that of a scientist, it cannot be denied that being a teacher requires a unique kind of expertise. Along with content knowledge of the subject and the pedagogical knowledge of the methods of teaching, it is the pedagogical content knowledge (how to teach a particular concept or topic) that differentiates teachers from scientists as suggested by Shulman [18]. Pedagogical content knowledge, a unique component in the profession of teachers, is based on how teachers relate their pedagogical knowledge to their subject matter knowledge [19]. In the words of Gudmundsdottir [20], pedagogical content knowledge is a form of knowledge that makes science teachers ‘teachers’ rather than scientists. It is not necessarily the quality or quantity of the subject matter knowledge that differentiates teachers from scientists, but in how that knowledge is organized and used.

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The uniqueness of the teaching process is that it requires teachers to ‘transform’ their subject matter knowledge for the purpose of teaching [18]. This transformation as mentioned by [19], occurs as “the teacher critically reflects on and interprets the subject matter; finds multiple ways to represent the information as analogies, metaphors, examples, problems, demonstrations, and classroom activities; adapts the material to students’ developmental levels and abilities, prior knowledge, and misconceptions; and finally tailors the material to those specific individuals or groups of students to whom the information will be taught”. On the contrary, a scientist’s knowledge is organized from a research perspective and is used for developing new knowledge in the field. To conclude, it can be said that there is a substantial difference between the profession of a scientist and a science teacher which provides an edge to scientists, though both emanate from the same subject. Similarly, other professions of science are also there which display differences with each other making some of these highly desirable and thus carrying a status.

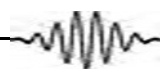


## Significance of Debates in Science

The evolutionary character of science sheds some light over its dynamic nature as evident from some debates underlying beneath its philosophical foundations. The globally accepted, dynamic/static (or both) status of science leaves it in an undecipherable position. The unbound perspectives about science coming from different standpoints enlighten the very idea of science being a debatable structure of knowledge. As mentioned by Mohapatra and Mahapatra [10], it is both the dynamic and the static view that reflects the dual nature of science. In other words, science keeps on accumulating concepts and theories subject to modifications through ongoing empirical observations. Scientific concepts keep evolving through experiments and observations leaving scope for further experiments and observations. Lederman [11] distinguished the nature of science from the scientific processes as these are usually confused because of their overlapping. Lederman referred to NOS as the “epistemological underpinnings of the activities of science and the characteristics of the resulting knowledge”. This highlights that these two are not distinct, rather, they are intimately related. Sarukkai [4] pointed out to the different dimensions of science that exist because of the various aspects it encompasses. Science is viewed as a title due to its association with an authority that decides what science is. The scientific method is the essence of science because science is about being inquisitive as it asks ‘what’ and ‘why’ questions. Sarukkai also noted that science is a search for truth as it is based on the belief that only talks about the truths of the world though they are tentative and open to change.

The emerging issues concerning the nature of science as domain-general or domain-specific have been examined by Schizas *et al.*, [14]. The authors contributed to the understanding of science as domain-specific by comparing biology and physics besides addressing the differences between these sciences, assuming that individual science areas have their own character. The authors focused on unique ontological, methodological and epistemological features of Newtonian physics and the neo-Darwinian sci-

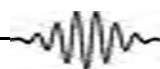
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entific worldviews, wherein, the former is based on assumptions grounded on positivism, and the latter provides an alternate understanding of nature of science, which is based on historical sciences. In the early 1970s, positivism was also criticized and rejected by almost all epistemological frameworks but its many tenets are still alive in scientists' minds.

More recent debates within science include perspectives such as; whether thought experiments transcend empiricism or not? First of all, it is required to understand as to what a thought experiment is. Generally, it is assumed that they are carried out in the mind and have a similarity to experience i.e. "we typically 'see' something happening in a thought experiment" [12]. Brown argued that thought experiments can transcend empiricism through an example of conceptualizing space as both finite and unbounded. While taking the examples from Lucretius's *De Rerum Natura*, Brown attempts to show that space is infinite by tossing a spear at the boundary of the universe. If the spear flies through, it does not have a boundary and if it comes back, then definitely there is something beyond the edge of the space (a cosmic wall that might have stopped the spear) which shows that space is infinite. It means that thought experiments make us visualize some situation, carry out an operation and see what happens. Though empirical concepts are used, it is not necessary that empirical test will be carried out. It was concluded that some thought experiments transcend experience. On the other hand, Norton [22] puts a contrary view that thought experiments do not transcend empiricism and perform no epistemic magic. Another on-going debate roams around the aspect of probability if it captures the logic of scientific confirmation or justification. Even after a plethora of arguments concerning the nature of science, all science educators, philosophers or sociologists came to a consensus about it and concluded that scientific knowledge is tentative, based on empirical evidence, and embedded in socio-cultural contexts. "Crucial decisions regarding what should be taught about NOS are still being addressed by the science education community as... defining science is no easy task" [14]. Therefore, NOS is still a debatable

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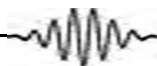
issue in the fraternity of sciences.

## Conclusion

An important finding that emerged out of the discussion is that the conceptual framework and the methodological practices in science, both change over time. Also, the dialogical processes of theory development continue to shape scientific knowledge and scientific practices. Though the existence of inconsistency in science has been played down, there are apparently circumstances in which it should be emphasized and utilized. Just like Darwin's theory of evolution that has developed since initial concepts, scientific enterprise too is not a static idea, but a growing concept added to by scientific observation, testing, and debate. Acknowledged equally by science educators regarding the unsettled nature of science, it is evident that science is evolutionary, debatable and hierarchical.

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