A Brief History of Science, Part 5: Development of the scientific method

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WE HAVE SEEN in the previous instalment of this essay that, in the last decade of the sixteenth century and the early part of the seventeenth, a revolt was brewing in the cultural landscape of Europe. More and more people started looking beyond the belief-system of the Church, and sought truth for themselves beyond the holy books. In scientific sphere, the revolt found embodiment in Copernicus, Bruno, Kepler, Tycho Brahe, and Galileo. The Church tried its best to suppress the rebellion in the sphere of ideas by punishing the heretics. But after the effort of Galileo, when the new thinking slowly spread among the public, there was no way to contain it. The heliocentric view of the universe came to be accepted among the learned people.

Once this age old mental road-block was removed, people started questioning the ideas in other spheres that had been believed for ages. They wanted to take a fresh look at everything. They wanted to learn the truth about nature without carrying the baggage of age-old beliefs. But the problem was: How to know the truth about the different phenomena? How should one approach? What should be the method of seeking truth?

At this critical juncture, three people laid out the path of doing science. They were Galileo Galilei in Italy, Francis Bacon in England, and René Descartes (pronounced *De-Carte*) in Holland. In this instalment of the essay, we shall delve upon the path they laid which opened up new vistas for science.

Prophets of the Scientific Age

Galileo Galilei

Galileo Galilei (1564-1642) was the central figure in the scientific renaissance in Italy. His contribution was described in detail in the last instalment. But, for the sake of completeness, we shall briefly discuss his contribution to the method of science. He did not write any philosophical treatise to elaborate these ideas. But people learned these from the way he did his own research, from the method he himself followed.

First, he was instrumental in introducing the objective method in place of subjective method, in seeking an answer to any question. He introduced the idea that every line of thinking, every assertion, and every theory needs verification by experiment or observation.

Second, he emphasized the need to express quantities in terms of numbers, or generally, in terms of algebraic variables. So far one would describe nature only qualitatively, in a descriptive manner. So far one would talk about something being fast, slow, small, big, etc., without bothering to specify how fast, how slow, and what was

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the length of the object. Galileo emphasized the need for quantitative measurement as an integral part of observation, and the need for building theories relating these quantities.

Third, he showed that in any phenomenon there are factors that are essential in understanding the phenomenon, and there are also factors that are not essential and can confuse the central issue. So a scientist needs to separate out the essential from the other factors to bring the pattern to the fore, and build theories on the basis of that. For example, in his studies on the motion of the pendulum, he saw the pattern only when he focused on the essential and kept out of view factors like weight of the string, friction of air, etc. That is how he arrived at his conclusion that the period of oscillation of the pendulum is independent of the mass of the bob and the amplitude of oscillation, so long as the amplitude is small. Thus he laid foundation of the theory of simple harmonic motion which is at the base of much of physics even today.

Even though renaissance started in Italy, the flame was soon extinguished in a religious backlash and a wave of reformism. That is why we do not see much spark of the renaissance after Galileo and his disciples like Torricelli (1608-1647). The centre of activity shifted to Holland and England, where the resurgent merchant class was on an ascent and was beginning to wield political power. Francis Bacon and René Descartes were contemporaries of Galileo in these two countries.


Francis Bacon (1561-1626)

Francis Bacon

Francis Bacon was one of the leading figures in natural philosophy and in the field of scientific methodology in the period of transition from the Renaissance to the early modern era. As a lawyer, member of Parliament, and Queen's Counsel, Bacon wrote extensively on questions of law, state, and politics, but in the later years devoted his time to proposing the method that scientific enquiry should follow. He was not really a scientist, but he expressed the aspirations of the time in clearest possible terms—to break free of the earlier belief systems, to build the correct idea of nature by actual observations and experimentations.

He argued that, so far we have wasted our time harbouring old belief systems and have not observed nature critically. The need of the time is to build the correct knowledge about nature by direct observation. This has to be done on all kinds of phenomena on a very large scale—which cannot be done by any individual scientist working alone. So he advocated collective endeavour of scientists to obtain a mass of data. According to his prescription, after the mass of observational data are obtained, the scientists should try to extract the general features from that, to build theories following inductive logic.

The noted historian of science Prof. J. D. Bernal writes: "With his empirical bent, Series Article

Inductive and deductive logic

All human activities are conducted following logical reasoning. Most of the time we apply logic unconsciously, but there is always some logic ingrained in the decisions we make in order to conduct the day-to-day life. Philosophers have shown that such logic can be broadly divided into two categories—inductive, and deductive.

Suppose you are going out of you home, and upon seeing a cloudy sky, you put an umbrella in your bag. What was the logic behind this commonplace action? It is that, you have seen from your childhood that the sky becomes cloudy before it rains. You have seen it once, twice, thrice, and then your mind has constructed the link "If there is dark cloud in the sky, it may rain". This is an example of *inductive logic*, where we reach a general conclusion by repeated observation of an event. The repeated occurrence of a particular truth leads you to reach a general truth.

What do you do next? On a particular day, if you see dark cloud in the sky, you think 'today it may rain'. You take an umbrella along. What was the line of reasoning behind this action? This is called *deductive logic*, where, starting from a general truth, you reach the particular truth about a specific situation.

All human reasoning falls into one of these two categories. Man cannot proceed a single step without applying these two lines of reasoning—from the particular to the general, and then from the general to the particular. The first one is inductive, and the second one is deductive.

Bacon was inevitably an opponent of all pre-determined systems of nature; he believed that, given a well-organized and well equipped body of research workers the weight of facts would ultimately lead to truth."

Bacon also argued for science to be used for the betterment of mankind: "The true and lawful end of the sciences is that human life be enriched by the new discoveries and powers." Thus, Bacon anticipated the industrial revolution that came in the wake of the new discoveries.

To summarize, the Baconian approach was to collect extensive information about the facts of nature by direct observation, and then to obtain truth from the facts. Thus, his prescription for doing science was

Experiment $\rightarrow$ observation $\rightarrow$ inference.

The means of making it possible was to promote *organized science*. And the logical procedure to achieve this was *induction.*

René Descartes

René Descartes was a peculiar character, quite representative of the temperament of his time. He was a man of learning, but at the end of his formal studies, he was in doubt if all that he had learnt in the university was indeed true. So he travelled far and wide and took up a career in the army in order to gain varied experience. He later wrote, "I entirely abandoned the study of letters. Resolving to seek no knowledge other than that of which could be found in myself or else in the great book of the world, I spent the rest of my youth traveling, visiting courts and armies, mixing with people of diverse temperaments and ranks, gathering various experiences, testing myself in the situations which fortune offered me, and at all times reflecting upon whatever came my way so as to derive some profit from it."

After 1629 he settled in the Dutch republic, and devoted his time to the development of a method for the pursuit of science. He was about to publish his work when he learned about the trial of Galileo in 1633. Descartes then published his work in phases, taking care not to come in a direct conflict with the Church. Nevertheless, within a very short time he managed to replace the Church-propagated system of thought in the universities by his own 'system'.

The important aspect of his 'system' of thought is the role he ascribes to *reason*. Descartes is often regarded as the first thinker to emphasize the use of reason to develop the natural sciences. And in reasoning, he proposed four guiding principles:

1. Never to accept anything which is not confirmed to be true. In his language "never to accept anything for true which I did not clearly know to be such; that is to say, carefully to avoid precipitancy and prejudice, and to comprise nothing more in my judgement than what was presented to my mind so clearly and distinctly as to exclude all ground of doubt."

2. So far, philosophers asked grand questions (like "What is the meaning of life?" "How did the world come into being?" etc.) that were not easy to answer, and fell prey to speculative thinking. To avoid that, Descartes proposed to divide big questions into smaller parts, each of which is tractable. "To divide each of the difficulties under examination into as many parts as possible, and as might be necessary for its adequate answer."

3. As in geometry one starts from a few axioms to follow a path of deductive reasoning, to arrive at theorems, he proposed to follow the same course in other areas of science as well. "To conduct my thoughts in such order that, by commencing with objects the simplest and easiest to know, I might ascend little by little, and as it were, step by step, to the knowledge of the more complex."

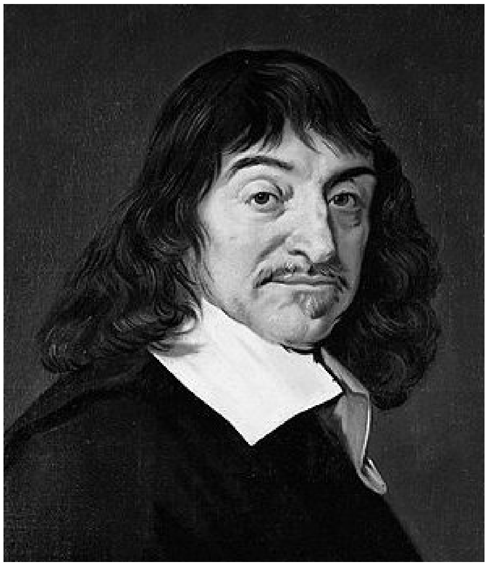
4. And last, to ensure completeness of the investigation: "in every case to make the enumerations so complete, and the reviews so general, that I might be assured that nothing was omitted."

(Quoted from his book "Discourse on Method")

Thus we see that logical reasoning, according to Descartes, was the way to reach truth. He underscored the importance of an analytical approach, the importance of asking the right questions. His way of doing science was more of an individual pursuit, where one starts from the premises that one knows positively to be true, and then applies deductive logic to arrive at the truth about more complex situations. To avoid logical errors in reasoning, he argued that the actual application of logic should take the form of mathematical deductions. Thus, he underscored the need of applying mathematics in reaching truth about nature. This assertion greatly influenced the later generations, most importantly, Newton.

Descartes being an accomplished mathematician, took steps to make mathematics amenable to physical reasoning by developing coordinate geometry. The coordinate system he developed is still called the "Cartesian" system after him. In this coordinate system the algebraic equations take the form of curves, and thus algebra and geometry, which were so far considered disconnected disciplines of mathematics, joined hands to pave way for a great development in mathematics.

He also underscored the importance



René Descartes (1596-1650)

of reducing grand questions into smaller tractable parts. This resulted in specialization in scientific disciplines, which proved to be crucial for the future success of science. It is only now that the problem of reductionism over-specialization is being felt, where the scientists are confined in narrow compartmentalized disciplines. Today's scientists are good at treating problems in isolation, forgetting to put the parts together to see the whole, in all its interconnections. This is called the problem of *reductionism*. But in the time of Descartes his prescription was truly valuable for the progress of science.

Even though his insistence on not accepting anything without proof was a blow to all sorts of religious faiths, he devised a clever way of avoiding clash with the Church. He demarcated the respective domains of science, and of theology by defining three 'qualities': the spacial extension and velocity of material objects—which can be measured and quantified—as the "primary" quality; the sense of colour, odour, taste, etc. as the "secondary" quality; and matters related to love, passion, ethics, morality, faith, etc., as "tertiary" quality. According to Descartes, science concerns itself mainly with the primary quality, and to a much lesser degree with the secondary quality. But the tertiary quality lies wholly outside its domain. This, according to Descartes, is the domain of theology. By putting it this way, he managed to obtain intellectual space for science to develop without interference from the religious authorities, so long as the scientists did not trespass into the religious sphere.

The great leap forward

From the above discussion, we see that the positions taken by Bacon and Descartes were complementary to each other. While Bacon stressed on organized science as a collective pursuit, Descartes saw science as an individual effort in analytical reasoning. While Bacon focused on inductive logic as the main tool in science, Descartes stressed the importance of deductive logic. While Bacon stressed on experimental science, Descartes stressed on theoretical research. In fact, application of both the aspects is crucial for the success of science. That is why, not individually, but together they set the path for the progress of science.

As a result of this, within a span of only fifty years from 1650 to 1700, we see science mature from the first tentative steps of a toddler to the confident stride of a young man.

The most important phenomenon in this period is the founding of the scientific societies. Prompted by Bacon's call for collective endeavour of scientists, people interested in science started meeting periodically, to discuss their findings, and to share their views and opinions on scientific subjects. Soon need was felt to make these formal. Towards this end the Royal Society of London was founded in 1662, and the Academie Royale des Sciences in France was founded in 1666.

By then the practical utility of science for improving the means of navigation, transport, and warfare had started to be understood by the people in power. So these societies had the "Royal" approval, though they had very little financial support. Most of the people who met, carried out research using their own resources.

Thus, science started nucleating around these societies, outside the ambit of the universities, as an endeavour of free people interested in science. The universities continued to be dominated by the old thinking. The Royal Society of London flourished under the able leadership of Robert Boyle (1627-1691) and Robert Hooke (1635-1703).

Robert Boyle (1627-1691)

Though Boyle is most known for the gas law named after him, he had varied interests and pursued many directions of investigation. Hooke, his assistant, was the one who actually carried out the experiments. He independently did research on the character of elasticity and discovered what is known today as the Hooke's law. In Holland Leeuwenhoek devised the first microscope and saw what nobody had seen before: micro-organisms. He communicated with the Royal Society describing his findings. Soon Hooke conducted a systematic study of the micro-organisms, and published the monograph "Micrographia". In Italy Torricelli demonstrated the existence of vacuum. In Germany, Otto van Guericke invented an air-pump, and conducted his famous public demonstration where sixteen horses were needed to pull apart two hemispherical vessels evacuated of air. Boyle and Hooke improved the air pump, and showed that sound did not travel in the absence of air but light and magnetism were not affected. These are only glimpses of the outburst of scientific creativity unleashed in that period.

While physics and astronomy proceeded somewhat along the path charted out by Descartes, biology, geology, and chemistry more or less followed the path shown by Bacon. The historian of science Dr. A. R. Hall writes "This is most clearly true of the biological sciences; no Galileo could have defined the strategic ideas of geology or physiology which only emerged from the wider and deeper knowledge of facts obtained in the nineteenth century. Bacon's advice that solid facts, certified by experiment, should be collected and recorded was sound and practical; this track occupied chemistry and biology till towards the end of the next century." (A. R. Hall, "The Scientific Revolution, 1500-1800", Longman 1954, p.167)

But the centre of interest in those times were astronomy and mechanics. The meticulous observations and experiments opened up many questions that demanded a grand synthesis. That was provided by Newton, which will be the subject matter of the next instalment of this article. □