The Determinants of the Scientific Revolution[1]

2. Factors and Conceptual Frameworks

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In this article we discuss the more recent theories of the scientific revolution, the integration of mathematics with science and the importance of conceptual frameworks.

Later Theories of the Origin of the Scientific Revolution

So could it be that we have to look elsewhere for the solution of the problem? We now come to more recent theories of the scientific revolution.

Let us raise the problem as to what attracts brilliant minds to any particular activity such as science. Without giving a complete answer one can at least list some factors.

There may be stages in which a particular scientific activity is intellectually stimulating and there are a lot of interesting problems on the verge of getting solved. This would be an attraction to join the activity. These reasons have to do with the internal dynamics of the growth of science and may be termed internal factors.

Another factor may be the view the society at large takes of a particular activity. If society values it highly, for whatever reasons, it may encourage brilliant people to participate in it. The reasons of society may have to do with the self-image of the society, the utility of the activity to it or may refer to something more intangible. These reasons may be rooted in the technological, economic, intellectual and social life of the society. One could refer to these as external factors. We shall now try to isolate some of these factors.

Internal Factors

In this context it is instructive to look at medieval European science. Did later developments in physics, associated with Galileo, arise through natural development from earlier work on dynamics?

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Medieval Dynamics

Most text book writers on science give the impression that there is no such thing as Medieval European Science. Further whatever little science medieval Europe had was what they had inherited from Greece via the Arabs. Mach, in 1869 wrote in his famous and influential book *Science of Mechanics*, "dynamics was founded by Galileo...., no part of the knowledge and ideas on this subject with which we are now so familiar existed in Galileo's time, but.....Galileo had to create these ideas and means for us" (18).

Since Mach's time a lot of work has been done on medieval intellectual history and, without detracting from Galileo's achievements and greatness, one has to now admit that there was a flourishing tradition of work in mechanics in medieval times. The credit for bringing this change of view, and starting the field of research in the field of medieval mechanics, goes essentially to the French catholic physicist Pierre Duhem.

Duhem, on the basis of his studies of medieval manuscripts, discovered the work of the scholastic teachers of natural philosophy, at the universities of Oxford and Paris, John Buridan, Albert of Saxony, Thomas Bradwardine, Nicole Oresme and others – in the fourteenth century. He published his work during the first two decades of this century (19). He claimed that Galileo was not an originator of modern dynamics but was only a vigorous defender of this earlier school of medieval dynamics against the authority of Aristotle and Averroes restored by the Italian renaissance. He would have liked to thus put the origin of scientific revolution back into the fourteenth century and give the credit of the scientific revolution to the schoolmen.

The further work on the history of the medieval science by Maier, Moody, Claggett, Crombie and others has of course led to a reappraisal of Duhem's thesis (20). Galileo did contribute key novel ideas to dynamics. The 'impetus' theory of John Buridan, at best, can be regarded as a precursor of his work. All the same he had a tradition of work in mechanics behind him. There is thus a certain amount of evolution also in the scientific revolution. Considering the fact that the Chinese did not develop such a tradition in mechanics, the importance of the schoolmen in channeling the discussion on to mechanics, and especially to problem of uniformly accelerated motion, cannot be denied. Galileo might not have worked in dynamics without it. It is amusing that it was these discussions on mechanics by the schoolmen which were denounced as arid by humanists, like Erasmus, of the European Renaissance.

In the Indian context there was some amount of discussion on the principles of mechanics

in the schools of Nyaya and Vaishesik Philosophy. These however never focussed on precise problems, like that of uniformly accelerated motion, and did not use mathematics in their discussion as was attempted by schoolmen at Oxford and Paris. As such they remained unproductive (21).

Integration of Mathematics with Science

One may note that in Europe the importance attached to a study of Aristotelian logic in the fourteenth century had shifted to the study of mathematics by the seventeenth century. How did this change come about? Was it a natural development out of the work of medieval schoolmen ? That this was so is maintained by Clagget and others.

E A Burtt, in his remarkable book *The Metaphysical Foundations of Modern Physical Science* (1924), argued however that the renewed emphasis on mathematics was due to a revival of Platonism during the Renaissance. A Koyre also is of the same view. To quote Burtt " the greatest point of conflict between the dominant Aristotelianism and this somewhat submerged but still pervasive Platonism. The latter regarded universal mathematics of nature as legitimate.....; the universe is fundamentally geometrical; it's ultimate constituents are nothing but limited portions of space; as a whole it presents a simple, beautiful, geometrical harmony. On the other hand the orthodox Aristotelian school minimized the importance of mathematics. Quantity was only one of the ten predicaments and not the most important. Mathematics was assigned an intermediate dignity between metaphysics and physics. Nature was fundamentally qualitative as well as quantitative; the key to the highest knowledge must, therefore, be logic rather than mathematics. With the mathematical sciences allotted this subordinate place in his philosophy, it could not but appear ridiculous to an Aristotelian for any one to suggest that his whole view of nature be set aside in the interest of a simpler but more harmonious geometrical astronomy. Whereas for a Platonist (especially as Platonism was understood at that time) it would appear a most natural, though still radical step, involving as it did the homogeneity of substance throughout the whole visible cosmos. However, Copernicus could take the step because, in addition to motive factors already discussed, he had definitely placed himself in this dissenting Platonic movement" (22).

External Factors

E Zilsel however attributes this development, i.e. an emphasis on mathematics, in particular, and the scientific revolution itself in general to the advanced economy and the

growth of rational, as opposed to empirical, technology (23). Let us now look at these social, economic and technological factors.

Social, Economic and Technological Factors

Friedrich Engels in a letter to Starkenburg written in Jan. 1894, emphasised these factors: "If , as you say, technique largely depends on the state of science, science depends far more still on the *state* and the *requirements* of technique. If society has a technical need, that helps science forward more than ten universities. The whole of hydrostatics (Torricelli etc.) was called forth by the necessity for regulating the mountain streams of Italy in the sixteenth and seventeenth centuries. But unfortunately it has become the custom in Germany to write the history of sciences as if it had fallen from the skies" (24).

Zilsel was among the earliest to take this Marxist point of view seriously. He connected the scientific revolution with the rise of capitalism in Europe. He pointed out that a number of characteristics of this early capitalism were conducive to the rise of scientific spirit. These are as follows:

(i) In the feudal middle age the knights in their castles and clerics in their monasteries in the countryside were the dominant elements of the society. With capitalism the focus shifted to towns and to merchants and craftsmen. Science, not being a military or other worldly pursuit, was more likely to develop in the new setting.

(ii) The rapid growth of machinery at this period encouraged rational, as opposed to magical thinking and provided real-life problems to be solved by science.

(iii) The hold of groups, such as guilds of craftsmen, and traditions weakened on people. People had to act as individuals, in competition with others, and not just as members of some umbrella-group. The rise of individualism was good for rational inquiry.

Parenthetically we may note that the lack of individualism and the hold of caste and other groups may have done their damage in India.

(iv) The base of capitalism is calculation and measurement as reflected in bookkeeping and the use of machines, not only for the production of goods but also for checking the quality and quantity of raw materials and output products. Luca Pacioli's *Summa de arthmetica* (Venice, 1494), the best textbook of its period, deals with double entry bookkeeping as well. The famous Dutch scientist Simon Stevin, known for his early

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work on mechanics, also deals with it. Stevin dedicated his paper containing the first description of decimal fractions "To all astronomers, surveyors, measures of tapestry, barrels and other things, to all mintmasters and merchants.....". The celebrated N Copernicus, whom we mentioned in connection with relationship of Platonism with mathematics, wrote one of the earliest tracts on reform of the monetary system.

At the time of Renaissance, the university educated scholars and humanistic literati, or the intellectual elite in general, were socially in the upper classes together with rich nobles, merchants and bankers. The intellectual elite used Latin somewhat like the Indian intellectual elite using English at present or Sanskrit in ancient times. They strongly adhered to the Greek prejudice against manual labour which was born out of theirs being a slavery-based society. Thus university-trained physicians were intellectually content to write commentaries on Galen. The surgeons belonged with barbers and midwives, as was true in rural India even fifty years ago. Craftsmen, who worked with their hands, were beneath the notice of intellectuals. Even artists were considered no better than white washers. It is these craftsmen who were involved with the technological discoveries of the age such as the mariner's compass and guns, construction of paper and wire mills, blast furnaces and a host of other such things. They on the whole used the vernacular and did not have a formal education. The separation of Head and Hand, remarked on by B Farrington–historian of Greek Science – was still very much there (1) [2].

As the pace of development quickened some of the superior craftsmen, i.e. those who needed more scientific knowledge for their work in contrast to others, such as artist-engineers, surgeons, instrument makers, surveyors, navigators and gunners made contact with university intellectuals. They also wrote various manuals or texts in the vernacular for the use of their friends in their profession. At a certain stage in the development in technology the social barrier was breached and intellectuals began taking interest in the work of these superior artisans. We may remark that Galileo (1564-1642) was the first university-trained writer to write in a vernacular (in this case, Italian) as opposed to Latin. Lynn White Jr, author of that classic book *Medieval Technology and Social Change* (1962), has also argued that the roots of Galileo's thought "lay not only in the alluvium of

[2] See Part I for this reference.

inherited speculative and mathematical science but also in contemporary engineering". Galileo, indeed, opens his book *Discourses* (1638) with a remarkable description of the Venice arsenal which is seen by him as something leading to scientific thinking. W Gilbert's book *De Magnete* (1600) was the first book by an academic based on his own experimental work.

According to Zilsel "the real science was born" when these two groups, i.e. academics and superior craftsman, came together after about 1550 A D. The theoretical and experimental methods could be unified thereby at last. Similar views have been expressed by J G Crowther, J H Randall and others (25).

Science and Society in Asia

We have already referred to Al-Biruni's comments on Brahmagupta. Debiprasad Chattopadhyay, in his remarkable book *Science and Society in Ancient India* has analysed the state of medical science and the status of physicians (26). The physicians of ancient India, as represented in Charak and Susruta Samhita and other medical texts, had developed a remarkably modern scientific outlook. They were however regarded quite low in the social scale. The Dharma Sutras of Apastamba has the admonition "The food given by a physician, a surgeon, a hunter, a fowler, an unfaithful wife or eunuch must not be eaten". In case there is any doubt about the company in which a medical doctor is supposed to be, Gautam Dharmasutra adds criminals and such other persons to the list. Artisans are also included in the same list. Food however may be accepted from "a trader who is not an artisan". According to Manu "the food received from a doctor is as vile as pus". Bhishma in Mahabharat also agrees with Manu as he asserts that "a gift offered to a physician becomes as vile as pus and blood". According to Manu the practice of medicine must be restricted to base born "Ambasthas". Of course one must emphasise here that these Dharmasutras represent the views and prejudices of priestly classes and these were probably not the secular laws of the land. All the same the debilitating effects of such social reception of the science of medicine were clearly not conducive to a scientific revolution. Being also a slave-owning society there was probably not much motivation for an improvement of technology. The head and hand remained, generally speaking, in isolation, even opposition, to each other in ancient India just as in ancient Greece.

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The case of Chinese society is somewhat different and a little more problematical. They had bureaucratic feudalism and the society was ruled by civil servants (mandarins) who were chosen on the basis of a competitive civil service examination based on the classics. Slave labour was not an important ingredient and there was a money economy. Of course merchants did not have much prestige. The mandarins and skilled artisans had a chance to interact and there was state support for large projects such as hydraulic ones. Of course as a result it can be fairly asserted that Chinese technology in the period of a thousand years before 1500 A D was probably the most advanced in the world. Still neither the scientific revolution, nor the transition to capitalism, did come about (27).

The Importance of Conceptual Frameworks

We have tried to give above a flavour of various theories on the origins of scientific revolution. None of them is totally satisfactory by itself. All of them probably reflect some aspect or other of the truth.

The basic difficulty in understanding the origins of scientific revolution, as it must have become clear by now, is that it is a unique event. It happened only once. We could regard it as a miracle and leave it at that as miracles cannot be understood. This course we do not pursue, or believe, as it leaves us intellectually dissatisfied. The method, we have followed above, for the elucidation of the origins relies heavily on a comparative study of science, technology and society in various ancient civilisations.

In the microcosm of the development of a particular scientific activity it always appears that the internal factors are dominant but when one views the development of scientific activity as a whole, as a macrocosm, the importance of external factors is very much brought out. External factors seemed all favourable to modern science arising in China and yet, as we noted earlier, it did not take place. Could it be that these civilisations lacked the appropriate conceptual frameworks?

It has been persuasively argued that the European consciousness underwent a drastic change from aural-oral mode to visual mode as a result of the impact of the printed word

(28) due to the Gutenberg revolution (1450 A.D.) Could this have caused the scientific revolution as Walter Ong seems to suggest in his study of Ramus (29)? But if one argues along these lines one should also explain the Chinese case who, after all, were the original 'printed word' people.

Could it be that missing conceptual structure was "a divine law over non-human nature" which was there in Europe and which began to be taken seriously at the time of Renaissance?

According to Needham, Chinese did not develop such a conception from their conception of human law. They had a bad experience of legal precision during the period of dominance of 'School of Legalists'. Besides the universe was conceived as a harmony in which different parts behaved according to their intrinsic nature and not because of some law imposed from outside. Chinese also did not develop the concept of a 'godhead' who acts as a divine law giver. In sixteenth century Europe, a cock could be prosecuted for laying an egg and sentenced to being burnt alive as it was considered 'a heinous and unnatural crime'.

There is an early recorded example of such a persecution from Basel in 1474 and a late one in 1730 from Switzerland. Such a prosecution would have been considered ludicrous in China but, all the same, one wonders with Needham, "Whether the state of mind in which an egg-laying cock could be prosecuted at law was necessary in a culture which should later on have the property of producing a Kepler" (30).

Cecil Powell agrees with this view and points out, "A confidence of order in nature, of the existence of laws of nature which men can aspire to elucidate, was an essential condition for the emergence of modern science in Western Europe, rather than in another civilisation, such as the Chinese, of which the thought was in some ways more sophisticated, but in which nature tended to be regarded as inscrutable". He goes on to express it in a more lively way. "Thus when the Jesuit missionaries first visited China and explained to the Chinese the Western view that the behavior of things is ordered by the laws of nature, they were received with polite scepticism. "We understand", said the Chinese, "that a human law giver can make laws, and establish sanctions to secure their observance. But surely that presupposes understanding on the part of those governed. Are you suggesting to us that air and water, sticks and stones have understanding?""(31).

It may be pointed out that ancient Greeks did not have a conception of natural law.

Unfortunately for them, being a slave owning society, external social factors were not conducive to bring the head and hand together. It is not totally clear as to what extent we had the concept of a natural law in India but we had similar inhibiting social factors as in ancient Greece. In fact the two cases are quite analogous. Islamic middle east probably missed out on the incipient scientific revolution probably more due to theological intolerance and political upheavals leading to a destruction of their intellectual centres. The Chinese did not develop a conceptual framework involving natural law. It would seem that there is not a single overriding determining factor which caused the scientific revolution in Western Europe. There was a concatenation of a number of determinants and a chemistry or interaction among them.

Concluding Remarks

Clearly the above analysis of the problem of the origins of the scientific revolution is tentative and is meant to stimulate further work and discussion. We may note that the study of ancient and medieval Indian science is still in its early stages. Nothing comparable to what was achieved by Needham and others for Chinese science, and what is available for a study of Greek science, exists. Apart from making reliable editions of the needed texts dealing with ancient and medieval Indian science, clearly the first priority, we have to move on to the next stage of their critical analysis. Their achievements have to be analysed in the light of our present knowledge e.g. how many of the chemical preparations given there make sense? One has to study their social context e.g. who were the users of the mathematical knowledge? How did the society view those who pursued scientific work? One has to be clear about the conceptual frameworks which were used by them. Did we have a concept of 'natural law'? What happened to the vedic concept of Rta later? A study of the factors promoting or inhibiting an implant of scientific culture in non-western countries at present might also teach us something more about the origins of the scientific revolution itself. A study of the introduction of science in Japan during the Meiji period would clearly be interesting in this connection.

We may, further, draw attention to the cultural renaissance which took place towards the end of last century in India. This period produced people like Bankim Chatterji, Ishwar Chandra Vidyasagar, Ram Mohan Roy, Keshub Sen in the humanities; Ramakrishna, Vivekananda and Dayananda in religion. In science we had Ashutosh Mukherjee, J C Bose, P C Ray and the foundation of the Indian Association for the Cultivation of Science (1876) by Mahendralal Sircar. This movement later produced C V Raman, M N Saha, S N Bose and others. This presents itself as a small scale version of what

happened in Europe during 1450-1700 A.D. when modern science arose there. A deeper study of the social, economic, technological and intellectual aspects of the history of this period of Indian history might be an illuminating one.

Suggested Reading

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24. **Engels' letter is reprinted in Kearny, Ref. 6. p. 64-66**
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31. **C F Powell, "Scientific World' 9, (3), 4-8 (1965) reprinted in E.H.S. Burhop, W.O. Lock and M.G.K. Menon, *Selected papers of Cecil Frank Powell*, North Holland, Amsterdam (1972).**

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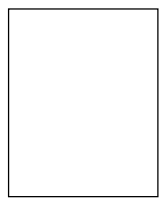

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