The Determinants of the Scientific Revolution[1]

1. Early Thinking

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This article gives an in-depth insight into the path leading to the Scientific Revolution which includes ancient theories of science and modern science and technology.

Introduction

The Scientific Revolution

There has always been a certain amount of technological knowledge in every human society. In fact the origin of technology may even be prehuman as studies on primate behaviour suggest. As technology is a way to use our knowledge of nature to obtain a living from it, it is necessary for human survival under adverse conditions. It is also necessary to support humanity in large enough numbers under not so adverse conditions. The periods of history of human civilisation, like Paleolithic, Neolithic, Bronze-Copper age, Iron age, etc. in fact are named after the dominant material used in the technology of those periods. Further if by 'science' we refer to any system of thought which tries to make sense of nature then there has always been a certain amount of science as well. Ancient Greeks, Indians, Chinese and Arabs and others have many scientific and technological achievements to their credit (1-4).

Modern science and technology, originating in Western Europe during the period 1450-1700 A.D. is however quite different in nature (5, 6). At this period activities which come under the rubric of science and technology underwent a phase transition somewhat analogous to the change of state of the substance water from liquid state to solid (i.e. ice) state at freezing point. There is a continuity at the microscopic level in that the same water molecules with the same intermolecular forces are involved and yet there is a marked discontinuity at the macroscopic level in the properties of solid ice and liquid water. It is worthwhile contrasting the nature of ancient science and technology with its modern counterpart before proceeding further. Since as in modern science and technology the underpinning is provided by science, we shall first discuss the contrast between ancient and modern science.

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Ancient and Modern Science

Most of the ancient sciences were rather qualitative and imprecise. The reasons are as follows. One had still not thought of the procedure of forming precise hypotheses about nature and deriving their exact consequences which could then be tested. In the most sophisticated version of this procedure, which is rather the norm in physical sciences these days, these hypotheses are formulated in mathematical form and the consequences worked out therefrom are not just qualitative but also quantitative. In fact the importance of testing theories by subjecting nature to well formed questions through controlled arrangements, i.e. experiments, had also not been discovered yet. One has to appreciate that the idea of *experiments* involves looking at nature in 'artificially' contrived situations and is thus quite different from the idea of *observation* where one looks at nature as we find it 'naturally'. For example in astronomy only observations are possible as we have to look at astronomical objects as they are. We cannot set up controlled situations in astronomy and thus experimentation is not possible. To take things out of their normal context and to study them probably appeared to ancients as doing violence to the essence of natural phenomena and thus an undesirable thing to do in studying nature. In any case the idea of experimentation did not arise, or at least did not take root, in ancient times. In the absence of these procedures of formulating and validating understanding, i.e. the scientific method, it is very hard to make systematic progress and to discard or improve upon any particular theory. As such all kinds of plausible looking scientific ideas could coexist and, in fact, did. This is generally the situation with ancient science. There existed many great intellects of high calibre in the ancient world. There were also careful observers of natural phenomena of great reliability. What the ancient world lacked was not these things but the present scientific method. As Whitehead once said, "the essential discovery of modern science was the scientific method itself". It is the appreciation and practice of the scientific method which has led to the progress of science being cumulative and exponentially increasing instead of being erratic.

The only exception to the charge of impreciseness of ancient science was ancient astronomy. Astronomy was however regarded not as a branch of science but of mathematics. Physics was part of science and concerned with causes while astronomy was a mathematical art concerned only with description. This tradition survived until quite recently. Recall that astronomy was included in mathematics departments, and not in the departments of physics, in British universities in the early part of the present century. Even in astronomy, which was essentially positional astronomy in ancient times, one was satisfied with a phenomenological fit of the data on planetary positions and was not concerned with any deeper understanding.

Ancient and Modern Technology

Ancient technology was also empirical, ad hoc and with a rather small amount of theoretical underpinning. Again it was not possible to systematically improve the existing technologies. The contrast between traditional and modern technology is brought out in a rather vivid manner in the famous war novel *The Bridge on the River Kwai* by Pierre Boulle. There he contrasts the methods of building a bridge in the traditional Japanese manner and according to the modern scientific method by English prisoners of war (7). There is an incident in the book in which the captured British soldiers are supposed to build a bridge without the paraphernalia of western civilisation being available to them in those jungles. In the slap-dash traditional Japanese method of building a bridge, you take a few logs, put them there, put some more materials wherever you think it is weak and you sort of strengthen it by putting one more log and then the next test is when you pass the troops over it. If it survives, it is alright. If it does not, well, you strengthen it a little more. In contrast to this, the captured British General who is supposed to build this bridge, calls on the only qualified engineer he has to build it. Now this engineer proceeds very differently. First thing he does is, he sits down with the drawing board with a pencil, geometrical instruments and so on. Then he designs it in his mind. This designing involves a lot of calculations and design drawings before it is transferred to any material. Of course this method is not so quick, because when you do this, rather than rushing headlong into construction of the bridge, you lose a lot of time. Not only that, this method calls for a lot of data. You must know the strength of the materials, elastic properties, their weight-bearing capacities, and all kinds of things coded in forms of some quotients. Of course, these quotients are not available to him. So he has to do a rough and ready observation to deduce these quotients and so on.

The basic contrast is obvious between this modern method, which while it is initially slow, eventually leads to a better bridge, and the traditional method which is not susceptible to systematic improvement.

The Problem

Thus while all ancient high civilisations of Greece, Rome, India, China, Middle East and others had a certain amount of science and technology, they all suffered from a lack of the discovery of the 'scientific method' and did not develop into modern science and technology. Why was the discovery of the 'scientific method' not made in these high culture areas, which were way ahead of Western Europe 'at that period of time'. Why did modern science emerge in Western Europe during the period 1450-1700 A.D. ? What were the causes of this scientific revolution i.e. its determinants?

The recent superiority of Western nations, and not just in science and technology, dates from the scientific revolution and arises due to its having taken place in Western Europe. All nonwestern civilisations have been put on the defensive and must somehow adjust to changes induced in the world by the scientific revolution or stagnate and perish (8). Thus an enquiry into the determinants of the scientific revolution, despite its great academic interest, is for us in nonwestern nations of much more than academic interest. It has bearings on survival. Modern science and technology has still not developed deep roots in view of its rather recent introduction there. It could be that some of the factors which inhibited the growth of modern science and technology are still operative in these areas. One has therefore to understand these factors and to combat them if necessary.

A word about the methodology we use is not out of place here. We shall examine the various factors which have been put forward as the determining causes of the origin of the scientific revolution in Western Europe, i.e. its determinants, one by one and ask whether these causes were operative in other high civilisations and account for nonorigination of the scientific revolution there. That is we use comparative cultural contexts for gauging the importance of the various suggested determinants. Before coming to the more recent theories about " why the scientific revolution took place in Europe and not elsewhere?" let us first have a look at some of the earlier thinking about this question.

Early Theories of the Origins of the Scientific Revolution

Role of Genius

William Whewell, master of Trinity College, published his three volume *History of Inductive Science* in 1837. It is one of the earliest histories of science and, as such, he had to take some stand on the causes of the scientific revolution. He underlined the role played by unusual persons of genius.

Incidentally the name of Whewell, though primarily known now to historians and philosophers of science, has a claim to be better known by the scientific community at large. After all it was he who coined the words 'scientist' and 'physicist'. When Faraday wrote to him asking his advice about what to call the two electrodes it was he who, ignoring various suggestions by Faraday, wrote back that they should be called 'cathode; and 'anode' and that is what they are called. He also coined the words 'eocene', 'miocene' and 'pliocene' among others (9).

According to Whewell men of genius arise now and then who can ask the right sort of questions, think in right and productive directions and suggest the right answers. The

occurrence of such men is, naturally, a rare thing. Science progresses when these men arise and languishes or stagnates when they are not there. In fact it is hard not to be impressed by people like Copernicus (1473-1543), Kepler (1571-1630), Galileo (1564-1642) and Newton (1642-1727) who ushered in the scientific revolution. They are all physicists and astronomers, as these sciences spearheaded the breakthrough. Similar breakthroughs in biology such as that of William Harvey's on circulation of blood, or in chemistry associated with Lavoisier and others, came later. Incidentally A Koestler in his account *The Sleepwalkers* takes the view that the contribution of geniuses is achieved not through a conscious process but rather through a process akin to sleepwalking. They unwittingly stumble on to great discoveries (10).

This view of Whewell is quite popular and caters to our sense of hero worship. It is believed by probably most scientists atleast implicitly. It is subscribed to by many historians of science as well. A Koyre has emphasized the role of Galileo (11). G de Santillana has brought out the role of F Brunneleschi (1377-1446) (12). Whitehead called the seventeenth century as a 'Century of Genius'. Butterfield's *The Origins of Modern Science* is also pervaded by this viewpoint.

The real question about the role of geniuses is not about the quality and significance of their contribution. They, of course, contributed significantly. But is that the cause, or a prime cause, for the origin of the scientific revolution ? There have been persons of unusual brilliance in all periods and at all places. Persons like Plato (427-347 B.C.) and St Thomas Aquinas (1225-1274) in the West and persons like the Buddhist logician, Dinnaga (fl. 425) and the Hindu philosopher Sankaracarya (788-820) of the Vedanta School were such men in the intellectual field. But they were not attracted to science. Does it not depend on what a particular society considers worth while? Persons of unusual brilliance may decide to become leaders of trade and industry or become military commanders. Why were so many geniuses attracted to science at that particular period in European history?

Science vs. Theology

As is well known Galileo was forced to recant his scientific opinions before the inquisition. He confessed " I, Galileo, being in my seventieth year, being a prisoner and on my knees, and before your eminences, having before my eyes the Holy Gospel, which I touch with my hands, abjure, curse and detest the error and the heresy of the movement of the earth" (13). It is only recently that the church has relented and brought him back into the fold of the faithful.

Before Galileo there was Giordano Bruno (1547-1600) who was burned at the stake for his opinions about space being infinite. Copernicus also is known to have waited some thirty years before publishing his magnum opus *On the revolutions of the Heavenly Bodies*. In fact Copernicus received the book only on his death bed.

In view of these well known instances it may appear natural to agree with the thesis of Andrew Dickson White. He was the first President and the first Professor of History at Cornell University. He published his views in his book *A History of the Warfare of Science with Theology* in 1896. The book was published in the milieu in which Darwin's theory of evolution, and especially his views concerning *The Descent of Man* (1871) were subjects of intense debates. The appeal of the book is evident from the fact that it has been reprinted repeatedly e.g. in a Dover Edition in 1955 (13). White believed that, but for suppression by organised religion, modern science would have inevitably developed much earlier.

Is then theology the culprit ? Some support to this may be available in the Indian context as well. Al-Bīrūnī had already commented on it in his book on India (c. 1030 A.D.) (14). He first noted that "It is perfectly known to Hindu Astronomers that the moon is eclipsed by the shadow of the earth and the sun is eclipsed by the moon. Hereon they have based their computations in the astronomical handbooks and other works". He is therefore very surprised as to how Brahmagupta "notwithstanding the abundance of his knowledge and the sharpness of his intellect" could write "Some people think that the eclipse is not caused by the Head. This, however, is a foolish idea, for it is *he* in fact who eclipses.....For if the Head does not cause the eclipse, all the usages of Brahmans which they practice at the moment of an eclipse viz their rubbing themselves with warm oil, and other works of prescribed worship, would be illusory and not be rewarded by heavenly bliss. If a man declares these things to be illusory, he stands outside of the generally acknowledged dogma, and that is not allowed".

Al-Biruni's conclusion was "I, for my part, am inclined to the belief that that which made Brahmagupta speak the above mentioned words (which involve a sin against conscience) was something of a calamitous fate, like that of Socrates, which had befallen him.....".

Even in the Islamic world these high standards of integrity of scientific thought were found difficult to maintain later under theologian attack. The theologian al-Ghazzali's (1058-1111) attack on Islamic scientific tradition had enormous influence. Ibn-Rushd (1226-1198), known in Latin as Averroes, tried to answer it in his book *The Incoherence of the Incoherence* but this could not be heard. Santillana says "al-Ghazzali's famous eloquence, undistinguished

intellectually as it is and to us ethically uninspiring, went to building up the whirlwind of intolerance and blind fanaticism which tore down not only science, but the very school system, and the glorious ijtihad, the interpretation of the Quran" (15).

It looks clear that theology and other similar closed systems of thought and vested interests can and do hamper the progress of science, which is an open system of thought. But still the influence of these pressures cannot be the whole story in the later rise of modern science.

It has been argued that the clash between Galileo and the church was not inevitable and a trial in somewhat different circumstances may have found Galileo in the right (16). Merton, Mason and Hooykass have even argued that the protestant reformation may even have triggered the scientific revolution (16). As Thomas Sprat, an early Fellow of the newly formed Royal Society, noted "They both may lay an equal claim to the word Reformation; the one having encompassed it in Religion, the other (i.e. the Royal Society) purposing it in (Natural) Philosophy" (17). These are all debatable.

However, consideration of the Chinese case makes one pause for further thinking. Chinese Society has been rather free of theological dogma in its long history. Confucianism, which was the dominant creed, was ethical rather than theological. Taoism also invites one to live in harmony with nature.

Suggested Reading

1. For ancient Greek Science one could consult

B. Farrington, *Greek Science*, Pelican (1961),

B. Farrington, *Head and Hand in Ancient Greece*, Watts, London (1947)

S. Sambursky, *The Physical World of the Greeks*, Routledge, London (1962)

M. Clagett, *Greek Science in Antiquity*, Collier Book, New York (1963)

G. Sarton, *A History of Science: Ancient Science Through the Golden Age of Greece*, John Wiley, New York (1964)

M.R. Cohen and I.E. Drabkin, *A Source Book in Greek Science*, Mc Graw Hill, New York (1948)

2. For Indian Science for a general account one could begin with *A Concise History of Science in India* edited by D.M. Bose, S.N. Sen and B.V. Subbarayappa. Indian National Science Academy, Delhi (1971). For an account, written with a different view point, see D.P. Chattopadhyaya, *Science and Society in Ancient India*, Research India Pub. Calcutta (1977).

3. The standard reference for Chinese Sciences is J. Needham and others, *Science and Civilisation in China*, Cambridge, 1954...

J. Needham, *The Grand Titration: Science and Society in East and West*, Toronto Univ. Press (1969).

Ho Peng Yoke, *An Introduction to Science and Civilization in China*, Oxford U.P. Delhi (1985).

4. For Islamic Science, a good one volume account is, S.H. Nasr, *Science and Civilization in Islam*, Plume Books, New York (1968) with a preface by G. de Santillana.

5. For some good accounts of this period, see
H. Butterfield, *The Origins of Modern Science* 1300-1800, Free Press, New York, (1965).
A R Hall, *The Scientific Revolution, 1500-1800*, Longmans, (1954).
M Boas, *The Scientific Renaissance, 1450-1650,* Harper and Brothers, New York, (1962)

6. Two reprint collections on the problems of scientific revolution are: *Origins of the Scientific Revolution,* Edited by H. Kearny, Longmans, Green and Co., London (1964);
The Scientific Revolution, Edited by V.L. Bullough, Holt, Rinehart and Winston, New York (1970).
For more recent scholarship, see D.C. Lindberg and R.S. Westman, *Reappraisals of the Scientific Revolution,* Cambridge U. Press, London (1990)

7. P. Boulle, *The Bridge on the River Kwai* Ch. 4

8. See e.g. K. Mendelssohn, *Science and Western Domination,* Thames and Hudson, London (1976).
D.R. Headrick: *The Tools of Empire: Technology and European Imperialism in the Nineteenth Century,* Oxford U.P., New York (1981).

9. P. Medawar: *The Art of the Soluble*, pp. 147-148 Methuen, London (1968).

10. A. Koestler, *The Sleepwalkers: A History of Man's Changing Vision of the Universe*, Grosset and Dunlap, New York (1963).

11. A. Koyre, *Etudes Galileenes* (3 volumes) Herman et Cie, Paris (1939), and *From Closed Space to Infinite Universe,* Harper Torchbooks (1958).

12. G. de Santillana. " The Role of Art in the Scientific Renaissance" *in Critical Problems in the History of Science* edited by M. Clagett, Wisconsin Univ. Madison (1959)
M. Kline, *Mathematics in Western Culture,* Oxford Univ. Press New York (1953).

13. As quoted in A.D. White, *A History of the Warfare of Science with Theology,* Dover, New York. See however, G. de Santillana, *The Crime of Galileo*, Time-Life reprint (1962) p. 337

14. Al-Biruni, *India,* Abridged Edition of Dr E.C. Sachau's English Translation, National Book Trust, Delhi (1983), Chapter 59 (p.215-217)

15. Ref. 4, p.xii

16. See e.g., G. de Santillana, Ref. 13 above
S.F. Mason in Kearny, Ref 6, p. 100-105
R. Hooykaas, *Religion and the Rise of Modern Science*, Eerdmans Grand Rapids (1972).

17. Quoted in S.F. Mason,. Ref . (16).

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