Chapter One

Science and Technology

Introduction

Science and Technology Policy, or Science Policy, for short,[1] is both an articulation and a descriptive plan; its central concerned is in directing the rate of scientific and technological knowledge through appropriate mechanisms for enhancing the socio-economic development of a society or a nation.[2] Science policy then is about the application of science and technology (S&T) towards some specific or social goals. It has never been formulated independently of the intellectual currents or societal contexts of the time. The study of science policy then has to be understood against the epistemological background of S&T and the social settings or agendas.

The discussion in this part is about the first; i.e. an overview of the nature, relationships, history, and philosophy of science and technology within the context of a social policy of science.

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[1] M.Daniel Jassen, "Towards a Science Policy", in *International Aspects of Technological Innovation, Science Policy Studies and Documents*, No.26. (Paris: UNESCO, 1971), p.33.
[2] Edward Shils, ed., *Criteria for Scientific Development: Public Policy and Social Goals*, (Massachusetts: The MIT Press, 1968), p.ix.

The Meanings of Science and Technology

The discourse of the meaning and relationship of S&T is of great importance to a study of S&T policy. How S & T is understood, either epistemologically or historigraphically, ultimately influences the outcome of a policy: whether a particular field will be service with funds or deprive of one may be related to the way it is understood within the hierarchy or classification of knowledge. Indeed it has been established that a particular understanding of the meanings and history of S & T could significantly influence the attitude of policy makers' decision in allocating funds for S & T development. For example, how the answer given to the epistemological question of whether technology is dependent on science or vice versa would affect drastically how a decision about the allocation of funds may be concluded. If science drives technology, than more money should be spent on science. However, if technology drives both itself and science, then the money should be directed to technology.[3] If the relationship is symmetrical and interdependence than the money should be equally made available to both.

Science and Technology, as currently understood and symbolised by a singular acronym S&T, is one perspective among many. Seen in the perspective of S&T the relationship between science and technology seems symmetrical, inseparable and indispensable to each other. If understood in its own terms, one independently from the other, a richer and far more complex image of either

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[3] Sally Gregory Kohlstedt & Margaret W. Rossiter, eds., *Historical Writing on American Science: Perspectives and Prospects*, (Baltimore: The Johns Hopskin University Press, 1986), p.229.

science or technology would emerge.

Definitions of Science

Science is said to be an objective knowledge. Paradoxically, the same cannot be said of the way it has been epistemologically defined. Science has been defined as an organised body of knowledge about the natural world.[4] It has also been defined as a form of human activity which is devoted to the production of theory related knowledge of natural phenomena and whose root function is to attain and enhance understanding of nature.[5]

However if we to take into account all the contemporary variations of definition of science there are, we can perhaps generalise the term 'science' as referring to the *scientific institution* (which includes the scientific workers and organisation of research), the research *process*, the scientific *method* or scientific *knowledge*. These four aspects of science are usually defined relative to each other.[6]

Science as an institution is that part of society which produces scientific knowledge by engaging in formal scientific research. The latter includes a systematic and institutionalised pursuit of acquiring knowledge by a corpus of disparate intellectual tools accepted by the scientific community. The corpus of those intellectual tools is known as the scientific method.[7]

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[4] Robert E. McGinn, *Science, Technology, and Society*, (New Jersey: Prentice Hall, 1991), p.15.
[5] Ibid, p.18.
[6] Ilkka Niiniluoto, *Is Science Progressive?*, (Boston: D.Reidel Publishing Company,1995), p.2.
[7] Ibid.

Epistemologically, there are many ways of how science can be understood. As early as the Greek tradition, science was understood in terms of the object of study. Plato, for example, regarded genuine knowledge (episteme) as a function of the invariant realms of ideas. The platonic science was thus essentially geometrical science that gave rational and provable knowledge about the ideal geometrical objects.[8]

By the 18th century science came to be more precisely define in terms of the mode of inquiry or by a method of rationality. For example, Hume defined science as abstract reasoning concerning quantity or number, involving experimental reasoning concerning matters of fact and existence.[9] More recently, Kemeny has defined science as a function of its method. The method is governed by acceptable standards of inference that includes the cycle of induction, deduction, and verification.[10]

Since the Industrial Revolution, science has been conveniently divided into basic or pure science, and the applied science. There have been suggestions that there are very little epistemological justifications to sustain this division, but it has been known as expediently useful. We still instinctively talk of science in terms of the "pure" and the "applied." Pure science is defined as the theoretical knowledge of the natural phenomena. Whilst applied science is the practical knowledge of natural phenomena or how to exploit nature for profitable ends. The

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[8] Norman Campbell, *What is Science*, (London: Methuen, 1921), p.21. Campbell defines science as the study of those judgements concerning which universal agreement can be obtained. Judgements here means the methods of science.

[9] David Hume, *Enquiries Concerning the Human Understanding and Concerning the Principles of Morals*. 2nd ed., (Oxford: Clarendon Press, 1902.), p.35.

[10] John George Kemeny, *A Philosopher Looks at Science*. (Princeton: N.J.Van Nostrand, 1959), p.176.

term 'applied science' is also used in two other perspectives. In one sense, it refers to all 'problem oriented' or 'mission oriented' research. In the other sense, applied science means problem oriented research which is based upon the results of basic research.[11] An interesting attempt to distinguish between the two was made by Feibleman. He defined applied science as the use of pure science for some practical human purpose. He further distinguishes applied science from technology (trial-and-error or skilled approaches derived from concrete experience) and engineering (application of technology to particular causes.)[12]

Definitions of Technology

Among technology management circles, technology has been simply understood as the "study of techniques".[13] The term "techniques" used here does not only refer to "some efficient way of doing manual things or getting practical things done." More so its meanings encompasses the idea of "material artefacts or hardware produced by a person, group or society".[14] As early as eighteenth century both the terms 'technique' and 'technology' have been widely used in contemporary literatures. Before the century, the term technique was synonymously used to refer to the 'arts and crafts'.[15]

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[11] Ilkka Niiniluoto, p.237.
[12] J.K. Feibleman, "Pure Science, Applied Science, Technology, Engineering: An Attempt at Definitions" in *Technology and Culture*, vol. 2., no.4, Fall 1964, (Chicago: University of Chicago Press, 1964), pp.305-317.
[13] Pierre Dussauge, Stuart Hart & Bernard Ramanantsoa, eds., *Strategic Technology Management*, (New York: John Wiley & Sons, 1992), p.6.
[14] Robert E. McGinn, p.14. According to McGinn, technique does not refer directly or primarily to particular individual devices, machines and so on. Rather it is to be understood as referring to generic types or kinds of devices, machines - to the watch, the axe, the videocassette recorder, the dishwasher, the personal computer and the knife rather than to my watch, your axe, and so on.
[15] Robert A. Burgelman, *Strategic Management of Technology and Innovation*, 2nd ed., (Chicago: Irwin, 1996), p.6. Robert argues that the century which saw the early stages of the industrial revolution was also the time when the need was felt to distinguish, in the area of productive processes, between arts and techniques. Arts stem from individual skills which can not be easily

In contemporary literatures, technique has been distinguished from technology in many different ways. Notably, the former is seen as a method of production at a given moment which is defined by the equipment and the management method used, while the latter is the whole package of the knowledge used in production".[16] Both perspectives are subsumed to the view that technology is the application of practical knowledge to satisfy economics needs through the creation, the distribution, the organisation and the industrial management of goods and services.[17]

Technology is also regarded as a cultural appendage. Indeed, it has been regarded as a distinctive form of cultural activity, just as art, law, sport, and religion are often used to refer as special expressions of human cultural practices.[18] Here then it is viewed as far more than about how a task is accomplished involving the clever use of machines, tools, paper and pen, computers, or procedures. In short, it is more than just about the special utilisation of knowledge and information transfer.[19]

However, within the industrial management circles technology is often seen as a specific process that produces a specific product. In this case the product

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systematised and reproduced. Techniques, in contrast, are the result of formalised and transmissible knowledge which is the basis for the development of all industrial activities. Thus, this evolution of language in the eighteenth century reflects a fundamental economic change. In the same way, the increasingly common use of the term technology instead of technique, which suggests a scientific understanding of technical evolution, may reflect the so-called 'new industrial revolution'. The technology label seems to be given primarily to the 'techniques' which are the cornerstones of the new industrial revolution, such as electronics, computers, and bio-technologies.

[16] Francois Chesan, "Science, Technology and Competitiveness", in *Science Policy Studies and Documents*, No. 1., (Paris: UNESCO, 1986), p.87.

[17] Ibid, p.8. This definition is based on a view of technology as the application of knowledge.

[18] Robert E. McGinn, , p.15.

[19] W. Randolph, "Matching Technology and the Design of Organisation Units", *Management Review*, Summer 1981, (Paris: OECD. 1981), p.13. This definition complements the 'know-how' that technique implies with the 'thinking' about know-how that is involved in technology.

is almost indistinguishable from the technology. Technology can also be synonymously identified with a manufacturing process. Technology can even be more broadly defined to include the way a company does business or attempts a task. Thus strategic management of an organisation is considered to be part and parcel of "the technology of the company" and not just the manufacturing process. In short, how technology is either defined or understood will have far reaching impact on the perceptions of the limit of a particular technology or a succession of limits of several primary technologies that together make up the larger or secondary technology. This in turn will have an influence on the processes of producing a product or the way of doing business.[20]

The above definitions do not negate the idea that technology is also about a set of instrumental rules that prescribe a rational course of action to achieve a predetermined goal. The achievements will then be evaluated on the basis of their usefulness and practical efficiency.[21] The instrumental rules in the definition are of two types; the rules based on (i) scientific inquiry and knowledge, and the (ii) pre-scientific rules. The pre-scientific rules could be an engineer's rule of thumb or expedience rules extracted from experience.[22]

The definitions of technology there often employed in official literatures in Malaysia are mostly of those prevalent within the management or industrial circles discussed above. If we were to reduce the salient features of those

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Technique is simple and easy to learn and put into practice; technology, in contrast, is complex and comprises techniques enhanced with knowledge and rational reflection on these techniques.

[20] R. Foster, *Innovation: The Attacker's Advantage* , (New York: Summit Books, 1986), pp.32-23.

[21] Mario Bunge Augusto, *Scientific Research* , vol.II. (New York: Springer Verlag, 1967), p.132.

[22] Karl A. Sroetmann, "The Assessment of Technology and Technological Policies", in *The Social Implications of the Scientific & Technological Revolution*, (Paris: UNESCO, 1981). p.209.

definitions, we could perhaps refer to just four major embodiments. They are the object-embodied physical facilities, person-embodied individual abilities, document-embodied known facts, and institutions-embodied organisational frameworks.[23]

Science and Technology

The relationship between science and technology has a history that has changed radically over the last two and a half millennia. This relationship has evolved from one of virtual isolation and mutual independence to one of intimate association and mutually beneficial interdependence.[24]

If we to look back to the history of science and technology to trace the relationships between the two, we would be struck by its complexity. For instance it would be extremely difficult to resolve the question whether technology comes first or science? or which is more important among the two in the culture? or whether science was more dependent on technology for its development or vice versa? From history we could see that in a particular civilisation, science seemed to be trailing behind technology, whilst in another the opposite was true.

More recently the notable relationships between the two are one of mutual dependence. Though in the early days of industrialisation, science seemed to follow industry; now it is part and parcel of the production process. As Bernal has

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[23] All the forms dynamically interact together enable the accomplishment of desired transformations. While physical facilities enhance the muscle-power and the brain-power of individual human beings, human abilities generate, operate, and maintain all physical facilities. Documented facts store accumulated knowledge so as to avoid reinventing the wheel. Organisational frameworks help plan, organise, activate, motivate, and control transformation operations. MOSTE, *Industrial Technology Development: A National Plan of Action*, (Kuala Lumpur: MOSTE, 1990), p.16.

[24] Caryl P. Haskins, *The Scientific Revolution and World Politics*, (New York: Harper & Row, 1963), p.30.

beautifully summed it up: "Science was learned from the wheel and pot, [then] it created the steam-engine and the dynamo."[25] In short, science and technology is inseparable and to all intents and purposes is appropriately referred to as a singular term, S & T.

Modern technology involve scientists who 'do' technology and technologists who function as scientists. The simplistic view that basic sciences generate all the knowledge which technologists then apply then will simply not help in understanding contemporary technology.[26] Contemporary experiences tend to affirm the notion that in terms of importance, science and technology to be on a par with each other. Practitioners of science as well as technology creatively extend and develop their existing sub-culture; but they also adopt and exploit some part of the culture of the other. They are in fact enmeshed in a symbiotic relationship."[27]

Science and Technology: Historical Background

The evolution of S&T, particularly the relationship between science and technology, from that of isolation from each other to that of interdependence can be more clearly understood by tracing their developments form antiquity to recent times.

In Antiquity the practice of science was pursued independent of technology. Technology consisted of arts and crafts like metalworking,

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[25] J.D. Bernal, *Science in History*,.(London: C.A. Watts, 1957) , p.31.
[26] E. Layton, "Conditions of Technological Development", Spiegel-Rosing & D. de Solla, eds., *Science, Technology and Society: A Cross Disciplinary Perspective*, (London: Lloyd's of London, 1977), p.210.
[27] B. Bernas, "The Science-Technology Relationship: A model and a query." in *Social Studies of Science* , An international review of research in the "S*ocial Dimensions of Science and Technology*", (London : Sage Publications, 1982), p.166.

architecture and medicine. While science, as natural philosophy, was a branch of philosophy and the formulation of scientific theories for the most part was by *a priori* method with little place for experimental testing or the empirical method of technology.[28]

The medieval period witnessed a turning point in the relation between "science" and technology. The separation that existed throughtout the antiquity up to the beginning of Middle Ages came to a halt as new methods of "science" were discovered that effected its relation with technology. This transformation was brought about by the discovery of new approaches to "scientific inquiry" such as in physics and mathematics and the use of mathematics in physical experiments. Mathematics, for the first time, was used in physical experiments. As a result well-made instruments were invented by using measurements and quantification. These great achievements are associated with the names of medieval natural philosophers and "scientists" such as Ibn al-Haitham, al-Biruni, Avecinna and others.

Ibn al-Haitham for the first time combined elaborate mathematical treatment with well-conceived physical models and careful experimentation. He, for example, conducted experiments to determine the rectilinear motion of light, the properties of the shadows, and the use of lenses. He even had a lathe on which he made curved lenses and mirrors for his experiments.[29] Al-Biruni a

[28] Robert E. McGinn, p.21. It is, further, argued that technology arose before the advent of pure science and derives chiefly from common experiences with practical problems. The building of the pyramids of Egypt represents a major technological feat without much recourse to an organised body of knowledge.

[29] Seyyed Hussein Nasr, *Science and Civilization in* Islam, (USA: Harvard University Press, 1968), p.129.

contemporary of Ibn al-Haitham also made among the most accurate measurement of specific densities known to modern times. [30]

The changes in method of science and S&T relation tell us more about the transformation that took place in the understanding of science as well as the development of the new methods of science during this period. For the first time, the Muslim philosopher scientists like those of Ibn al-Haitham, al-Biruni, Avecinna and others combined the theory and practice together. This is symbolized in the use of mathematics in physical experiments. In fact, this new pattern brought to light the relation between mathematics and physics. Through his works in optics, Ibn al-Haitham described experimentation as the relation between mathematics and physics.[31]

These novel ideas brought theory and practice close together. In fact the "artisan-philosophers" an aberration in ancient world, was more of a norm in Islam.[32] This pattern of thinking became wide spread in scientific and philosophical activities of that time. If one looks at the various fields of knowledge practised at the time, Muslim scholars always searched for both qualitative assertions and quantitative results. They did not look at one aspect at the expense of the other nor did they discriminate against other existing traditions. They based their choice on the usefulness and soundness of the ideas rather the

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[30] Brian Stock, *Science, Technology, and Economic Progress in the Early Middle Ages*, in David C. Lindberg, p.21. For some detail information on the status and achievements of science see the book by Seyyed Hussein Nasr quoted in footnote no.1.
[31] Roshdi Rahsed, "Islam and the Flowering of the Exact Sciences", in *Islam, Philosophy and Science*, Four Public Lectures organized by Unesco June 1980, (Paris: The UNESCO Press, 1981), p.155.
[32] Brian Stock, p.129.

traditions it came from. They adopted the existing ideas and by way of modification and integration developing the methods of knowledge further.

Muslim scientists combined the Greek and Indian sciences and through improvement and modification produced both qualitative assertions and quantitative results. In the case of numbers, for example, by combining Indian and Greek numerical operations Muslim scholars came up with new mathematical methods and concepts.. They harmonised the metaphysical aspect of the numerals as well as their quantitative aspects. The latter they showed by solving the contemporary problems in computation. By replacing the Roman numbers with new numbers the accuracy in computation was enhanced. Indeed the modern computation that made computers possible is indebted to the mathematical and numerous inventions of the Islamic medieval scholars.

Therefore during the medieval period one could say that science and technology for the first time was brought together. This closeness and interdependency was carried over to the next periods of Renaissance and Scientific and Industrial revolutions and continues today.

In Renaissance, which inherited the medieval method of science, the relation between science and technology remained mutual. The close relation between theory and practice continued. The Renaissance philosophers using the method developed in medieval period further extended the domain of experimentation. The Italian philosophers like Albert (1440-1472) and Leonardo da Vinci (1452-1519) played the leading role in the development of method of science in the Renaissance period. They also further discovered and developed a new methods of science that changed the role and status of science not only in relation to technology and also to other fields of knowledge too.

Albert was the first Renaissance philosopher to conduct physical experiments and apply mathematics in his experimentation.[33] Albert's experiments enhanced the application of science in developing technology. Leonardo a contemporary of Albert used the same method and made it the principle of his approach to science.

Albert like the medieval Muslim scientists approached science from a practical side. He believed that by applying science in developing technology, science would assume a practical position and role in human life. In doing this he, however, did not break up with the previous traditions. He in fact considered even the ancient sciences as a sound starting point, but not conclusive lacking practical applications. And thus he looked at observation and experimentation as the true methods of science.[34]

Leonardo defined the relation between science and technology as interdependent and mutual. One is not possible without the other, both need to be tied together to yield result and grow further. He even went further to state that those who rely on practical without science are like sailors without rudder on compass. True science, he held, began with observation; if mathematical reasoning could there be applied, greater certitude might be revealed.[35] Leanardo attempted to prove this method in his own practical works. He perused both kinds

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[33] Sir William Cecil Danpier, *A History of Science and technology: And its relation with philosophy and Religion*, (Cambridge: University Press, 1948), p.104.
[34] Ibid.
[35] Ibid.

of activities, working in scientific fields as diverse as anatomy, fluid mechanics, optics, and acoustics, and engineering specialities such as machine design, architecture, military engineering and weaponry. He also designed grand hydraulic projects dams slice gates waterwheels, canals, and locks.[36]

The medieval and Renaissance characters of S&T radically changed during the period known as Scientific Revolution.[37] During the Scientific Revolution, which marks the beginning of modern science, the relation of S&T took a different form, as new methods of scientific inquiry was discovered and adopted. Notable in this development was the novel use of mathematics in the understanding of nature. We know that mathematics has been used extensively by the Greek scholars of antiquity in the study nature. But the Greeks were more interested to use mathematics in the qualitative and symbolic sense with the ultimate aim of "saving the phenomena" rather than dissecting and analysing them. For the modern science scholar, as represented by Galileo, one of the most notable figure of the period, was in the emphasis of the role of quantitative mathematics: "the physical world was a separate and mathematical conception, piece of machinery, the action of any part of it was calculable."[38]

Between the 17th century to the early 19th centuries, technology influenced the practice of science in three ways: through provision of scientific

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[36] Ladisloo Reti, *The unknown Leonardo*, (New York: McGraw-Hill, 1974), pp.170-207.
[37] Hugh Kearny, *Science and Change: 1500-1700*, (New York: McGraw-Hill Book Company, 1981), p.56. The Scientific Revolution that occurred sometime during the sixteenth and seventeenth century centuries, is associated with Copernicus (1473-1543), Galileo (1564-1642) and Issac Newton (1642-1727). During this period, scientists adopted a new method of inquiry - the experimental method. Galileo set the tone of this experiment.
[38] Charles Singer, *A Short History of Scientific Ideas To 1900* , (Oxford University Press, 1959), p.257.

instruments, through giving rise to new metaphors, and by influencing the research agenda of science.[39] Evidently, as early as the seventeenth century, science grew at unprecedented rate, but its development by and large was dependent on the very instruments produced by contemporary technology. Technology then was largely arts and crafts driven, and science was yet to have any significant contribution to technology development. The empirical discoveries and the development of industrial processes in industries such as metals, textiles, brewing, and dyeing took place and advanced without being indebted to the contemporary advancement of fundamental scientific concepts.[40] In short, the growth of technology then was independent of that of science.

The genesis of science can be traced as far back as the ancient civilisations of Babylon, Assyria, and Egypt, where systematic records of events - particularly those related to astronomy - began to be compiled.[41] At a latter stage, beginning with the work of the pre-Socratic philosophers, speculative and abstract concepts about natural phenomena began to evolve, culminating in the work of Plato and later in the work of Aristotle. This allowed, for the first time in history, the ferment of the initiative to construct and relate abstract conceptions about the empirical perceptions of the world.[42]

The Greek civilisations put premium to science or rather natural philosophy. However, the same cannot be said for the Romans whose love of the

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[39] Robert E. McGinn, p.22.

[40] Peter Mathias, "Who Unbounded Prometheus? Science and Technical Change: 1600-1800", in Peter Mathias, ed., *Science and Society: 1600-1900*, (Britain: Cambridge University Press, 1972), p.54.

[41] J.D Bernal, *Science in History* , vol.1. (Cambridge, Mass., MIT Press, 1971), p.345.

[42] S.F. Masson, *A history of the Sciences* , (New York: Collier Books, 1962),

practical. arts and the sensual were legendary. During the Roman Empire the pursuit of science was not encouraged, and little of significance was added to the corpus of Greek science. The notable exception was the work carried out at the Ptolemian Academy in Alexandaria, where a relatively large number of scientific concepts and conceptual machines were developed.[43]

After the decline of the Roman empire, the Greek intellectual tradition was continued in the Byzantine Empire and in the Muslim world. The tradition was maintained and further developed, especially in the latter. Science was enriched further because Islam not only acted as a bridge between the civilisations of the Indus Valley and those of Western Europe, but also became the intellectual melting-pot for all the learnings between the two great civilisational regions of the time. Owing to that the Islamic Empire became the centre of intellectual activities during the Middle Ages.

The introduction of Muslim science (and to some authors in the West still claim that it was a reintroduction of Greek science) by the Muslims provided the foundation for the Renaissance of Europe's intellectual life.[44] The works of Copernicus, Vesalius, Gilbert, and Roger Bacon (who systematised the methodology of science of his age, with the emphasis on the empirical and

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[43] H. Hodges, *Technology in the Ancient World*, (Middlesex: Penguin Books, 1971), chap.7. Many engineering devices, which were to be reinvented centuries later during the industrial revolution, were anticipated by the members of this Academy. Water clocks, pumps, various mechanical devices for lifting weights, war machines, and even a steam turbine were developed by men like Hero, Ctesbius, and Philo. However, the materials of the day and the manufacturing crafts were not sufficiently advanced to translate the designs and experimental devices into fully usable machines.

[44] Seyyed Hossein Nasr, *Science and Civilisation in Islam*, (New York: New American Library, 1970), p.43. In this period, the Arabs translated almost all works done by the Greeks and reached Europe during a period ranging from the 11th to the 13th century.

inductive methods) sowed the seed of fermenting toward a fully-fledged scientific revolution in the succeeding centuries.[45]

The importance of the Middle Ages to the shaping of the Western mind was reiterated by Whitehead:

> "But for science something more is wanted than a general sense of the order in things. It needs but a sentence to point out how the habit of definite exact thought was implanted in the European mind by the long dominance of scholastic logic and scholastic divinity. The habit remained after the philosophy had been repudiated, the priceless habit of looking for an exact point and of sticking to it when found....

Whitehead suggests that medieval scholarships provide the meta-scientific foundations that are so important for the development of science:

> "I do not think, however, that I have even yet brought out the greatest contribution of medievalism to the formation of the scientific movement. I mean the inexpungable belief that every detailed occurrence can be correlated with its antecedents in a perfectly definite manner, exemplifying general principles. Without this belief the incredible labours of scientists would be without hope. It is this instinctive conviction, vividly poised before the imagination, which is the motive power of research: that there is a secret, a secret which can be unveiled. How has this conviction been so vividly implanted on the European mind?
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> ... there seems but one source for its origin. It must come from the medieval insistence on the rationality of God...."[46]

The Middle Ages, also, witnessed the refinement of productive techniques. Road building, construction of canals and waterways, improvements in shipbuilding and the introduction of new types of plows all took place during the early Middle Ages. These were to be followed by the development of crafts and guilds, by significant improvements in construction by the widespread use of watermills, and by the resurgence of technical activity stimulated by the contact

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[45] Charles Singer, The Dark Ages and the dawn of science, *From Magic to Science* , (New York, Dover Books, 1958),

[46] Alferd North Whitehead, *Science and Modern World*, 1[sst] eds., (The Macmillan Company, 1925), p.13.

with Eastern culture. These led to improvements in textiles, mosaics, irrigation, silks, paper, etc.

During this period a great variety of local technological responses, suited to the particularities of the local environment and widely diffused throughout the whole society were developed. Mumford has called this stock of technological responses the 'polytechnic heritage' of the Middle Ages and has pointed out:

> "The great feat of the medieval techniques, then, was that it was able to promote and absorb many important changes without losing the immense carryover of inventions and skills derived from earlier cultures. In this lies one of its vital points of superiority over the modern mode of monotechnics, which boosts of effecting, as fast and as far as possible, the technical achievement of earlier period.... Some of this polytechnic advantage was due to the fact that skills, the aesthetic judgement and appreciation, and the symbolic understanding were diffused throughout the whole community, not restricted to anyone caste and occupation. By their very nature, polytechnics could not be reduced to a single, standardised, uniform system, under centralised control."[47]

Medieval technology as polytechnic crafts continued to develop and diversify well into the late 16th century, following the pattern established throughout the Middle Ages and the Renaissance. But gradually, notably in the 17th century, the polytechnic crafts were replaced by more rigidly organised manufacturing methods. Traditional guilds began to break down, and a more tightly structured division of labour in manufacturing began to emerge. The reduction in technological variety took place concurrently with the development of the capitalist mode of production in which the worker was no longer the owner of the means of production. The major European nations of the time like France,

[47] L. Mumford, *The Pentagon of Power*, (New York: Harcout Brace Jovanovich, 1970), pp.140-141.

Sweden, and even Russia adopted the serial production process. The latter manufacturing process involved the division of many steps in which a worker performed only a part of an operation as opposed to be involved in every part of the process before. The new process was hastened by the contemporary needs of nation-states going to war with new weapons technology. Thus the demand on the efficient control of manufacturing arms. The serial production process become an essential and integral part of the arms factories requirements and manufacturing processes.[48]

The adoption of serial production process and the institutionalisation of new manufacturing processes paved the way for a transition from traditional manufacturing to modern industry. The transition was also facilitated by the development of new sources of power, particularly the steam engine, and by the development of metallurgy. The milestone of this development was large scale steel manufacturing and production of precision machines; so that machines could be used to produce more refine machines. In short, the shift from a polytechnic mode of production to a monotechnic manufacturing processes was partly driven by the need for greater efficiency and the need to address the issue of quantity versus quality.

The latter issue became more and more focussed with the dawn of the industrial revolution that began in Britain and overflow to the European continent. The industrial revolution was made possible by the ferment in the science and technology of the day. The two intellectual ferment - the growth of science and

[48] Ibid, pp.148-149.

the evolution of technology - began to interact more closely. This was evident by the middle of the 18th century. Since then the 'scientific revolution', which represents a breakthrough in understanding, and the 'industrial revolution', which represents a breakthrough in the adoption of technology for productive activities. moved complementarily toward an ongoing process of merger that would be completed only in the 20th century.

However, the account given in the preceding discussion is not to downplay the complexity of the relationship of science and technology throughout the ages. Given that as early as the 16th century, science contributed directly to the development of certain sector of contemporary technology. This was evident in the role of science in the development navigational and maritime technologies. The areas and intensity of interaction between science and technology was intensified during the 17th and 18th centuries. By the dawn of the industrial revolution, the relationship of science and technology became more evident in the development of new production processes and manufacturing practices. The latter statement, however, do need qualification, since we know that some breakthroughs were evidently made without any direct contribution from contemporary scientific knowledge. In fact it has been generally acknowledged that during the earlier stages of industrialisation process, the technical advances contributed more to the development of science than to the development of productive techniques. Bernal has pointed out:

> "The major transformation that characterise the great Industrial Revolution … …were made possible only by the availability of capital for making the

new machines. All of this might have happened without science, but it could not have been done so quickly."[49]

During the late 19th century, the predominance of empirically "trial-and-error" or "rule of the thumb" developed productive techniques soon gave way to the rise of new industrial activities based on scientific discoveries. Toward the end of the 19th century, the two industries where this transition was clearly visible were the electric and chemical industries, particularly involving the development of the telegraph, the telephone, and new synthetic materials. The interaction between science and industry during this century evidently took the form of scientific studies of established industrial processes, such as the use of steam engines and the production of steel. This development also instigate the ferment of new scientific theories and generalisations.

As the century progressed, a greater number of instances were to be found where scientific discoveries preceded the development of productive techniques. This led to the new phenomenon of systematic and premeditated invention and, at a later stage, to the emergence of the industrial laboratories. In the United States, this phenomenon was notably seen in the establishment of Arthur D. Little's laboratory in Boston and Edison's laboratory in Menlo Park, where their sole occupation was in the application of scientific research to the solution of technical problems in production.[50] Several other scientists and engineers from various disciplines in Europe worked under similar industrial-laboratories. These

[49] J.D. Bernal, vol.4., p.1229.
[50] L. Mumford, 1970, p.150.

laboratories were precursors that later became an integral part of the R & D unit of the modern industry.

In the early 20^{th} century, the interactions between science, technology, and production in the Western European countries, in the United States, Japan, and the Soviet Union. was influenced more by organised industrial laboratories than the individual inventor. The converse case was true in the last preceding century. This trend was further entrenched by the large-scale employment of scientists in a major war. Perhaps, for the first time in history, scientists was used actively in the World War I. They were responsible not only for improving cannons and guns but also for the development of new weapons of destruction. The best known was the introduction of chemical weapons and armoured vehicles, the precursor of the modern battle tanks. The former was credited to the scientists and the latter was credited to the engineers. The fruit of their labour trickled down into the civilian context as diffusion of scientific and technical skills, and by the improvements in the internal combustion engine technology. The latter made the mass production of automobiles possible.[51]

The period between the World War I and the next War saw another major mobilisation of scientists and technologists for a political or military cause. Perhaps one of the major by-products of that mobilisation was the advancement in nuclear physics. Notably, the American army's Manhattan Project to develop the atom bomb that was successfully dropped on the civilians of Japan. The other notable by-products of the war were rocket science and computers. There was also

[51] J.D. Bernal, *The Social Function of Science*, (Cambridge: MIT Press, 1967),p.34.

the expansion of the chemical industry as a result of the new discoveries in chemistry. The post-war period can be characterised as the age of S & T. This was characterised by unprecedented advances in major fields of modern science namely electronics, biology, chemistry, cybernetics, and many others. More importantly perhaps was the evident widespread use of the results of scientific research as a major source of improving productive techniques. In short, research and development activities have become an indispensable part of the industry.

According to Freeman:

> "What is distinctive about modern industrial research and development is its scale, its scientific content and the extent of its professional specialisation. A much greater art of technological progress is now attributable to research and development performed in specialised laboratories or pilot-plants by full time qualified staff ...

Freeman further outlined the major characteristics of the new development in the area of research and development. According to him;

> The professionalisation (of research and development) is associated with three main changes:
>
> (i) The increasing scientific character of technology. This applies not only to chemical and electronic processes but often to mechanical processes as well...
>
> (ii)The growing complexity of technology, for example, the partial replacement of 'batch' and 'one-off' systems of production by 'flow' and 'mass' production lines ...

(iii) The general trends towards the division of labour ...which gave some advantages to the specialised research laboratories, with their own highly trained manpower information services and scientific apparatus".[52]

Another by product, which is less tangible and by no means less important, was the diffusion throughout society of the values and the thought habits associated with the scientific and technological revolution. Indeed, the symbiosis of science and technology or production during the emergence of modern industry demanded a different outlook and values by the society. The idea that it is possible to understand, predict and control the phenomena around us and that man can transcend the limitations imposed by nature has had great influence on the social development of countries in the north. This is most evident in societies or nations that have an indigenous scientific and technological base. Ultimately these bases are anchored in the socio-economic values and structure of the society and thus will have consequences upon the values and structure of the economy and society. On this point Laden underscores the following:

"When all the complicating circumstances are stripped away - changing technology, shifting ratios of factor costs, diverse market structures in diverse political systems - two things remain and characterise any modern industrial system: rationality, which is the spirit of the institution, and change, which is rationality's logical corollary, for the appropriation of means to ends that is the essence of rationality implies a process of continuous adaptation. These fundamental characteristics have had in turn explicit consequences for the values and structure of the economy and society".[53]

[52] C. Freeman, *The Economics of Industrial Innovation*, (Middlesex: Penguin Books, 1974),p.5.
[53] D. Laden, *The Unbound Prometheus*, (Cambridge: Cambridge University Press, 1969), p.546.

Science and Technology: Philosophical Background

An understanding of the philosophical background of science and technology is essential for the epistemological analysis of an S & T policy. The scope of this study does not allow for a full account of the philosophical background of science and technology. However, for the purpose of the discussion here, a cursory sketch of the dominant philosophies of science of our time is in order. But contemporary philosophies of science could only be clearly understood against the background of the past.

The metaphysics of science or rather meta-science arose within the bosom of the Ionian philosophy of antiquity. Ionian cosmologists began exploring the ways to explain the natural phenomena and seek to explain the essence that constitute the world. They wondered about the quiddity of things and the ultimate forces that govern the universe.

Thales of Miletus (580 B.C.), the earliest Ionian philosopher known to us, assumed that the whole universe is natural, potentially explicable by ordinary knowledge and rational inquiry.[54] The Greeks have had been portrayed as generally obsessed, above all, by the desire for knowledge; more in the sense of explaining, than for mastering the processes of nature. It was the former that had driven the development of Greek philosophy.[55]

Benjamin Farrington classified the development of Greek philosophy and meta-science before Plato into three major divisions:

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[54] W.C. Dampier, *A History of Science: and its relation to philosophy and religion*, (Cambridge: Cambridge University Press, 1966), p.14.

[55] Indeed, philosophy was meant as the pursuit of all knowledge that included facts and data. cf. Earnest H. Hutten, *The Origins of Science: An Inquiry into the Foundations of Western Thought* , (London: George Allen and Unwin Ltd, 1962), p.34.

(i) The first is the Milesian achievement, which was an attempt to explain the phenomena of nature, including human nature, without supernatural intervention.[56]

(ii) The second phase is described as a rudimentary technique of interrogating nature by means of experiments. Where there was a series practice of observation and crude experimentation in Ionia.

(iii) Finally, the third phase represents the period when the connection between natural philosophy and techniques were established, which determined the early philosophy of nature.[57]

Plato (428-348 B.C.), although made great contribution to the development of logic and mathematics, however, ignored experimentation as being either impious or a base mechanical art.[58] His criticism of experiment, sense perception and mind in the process of cognition of the external world is taken to be discouraging the development of empirical science. Thus, in the words of Benjamin, Plato "not only did not contribute to positive science, but discouraged it."[59] This is perhaps too harsh a judgement, since Plato did make a contribution, but it was in the domain of meta-science and the used of symbolic mathematics in understanding nature.

Plato's disciple, Aristotle's (384-322 B.C) contribution however was in emphasising the very thing that his teacher had sought to devalue: empirical investigation. His other important contribution to science was in the codification

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[56] Benjamin Farrington, *Greek Science: Its Meaning for us*, (London: Penguin Books, 1949), p.93.
[57] Ibid, p.93.
[58] W.C. Dampier, *A History of Science: and its Relation with Philosophy and Religion* , (Cambridge: Cambridge University Press, 1966), p.28.
[59] Farrington, Benjamin. *Science in Antiquity*, (London: Oxford University Press, 1950), p.110.

of logic.[60] Aristotle was to left an undeletable mark on the succeeding generations of scholars from two major civilisations: the early Muslims and later Christians.

Aristotle occupied a special place among the Muslims' scholars. Among the latter he was known as the first wise man or first teacher. The Muslim philosophers and scientists translated much of Greek thought into Arabic. It was the earliest effort ever involving the translation of Greek learning into a foreign language. The Muslims successful translation of Greek intellectual corpus owed much to the availability of paper and improved book binding techniques. But the single most important factor for the success of the translation effort was probably due to the inherently sophisticated Arabic language that was perfect for expressing both philosophical and scientific concepts - a fact of considerable importance for the development of classical Islamic science.[61]

The Muslims expanded the idea of science inherited form earlier traditions of knowledge; they elaborated and clarified the methods, and affirmed the pre-eminence of natural philosophy, along with religious philosophy, within an Islamic epistemology of knowledge. The Muslims also broadened the practical disciplines to include those not mentioned by Aristotle or his Alexandrian students.[62]

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[60] Ibid, p.113.

[61] Ibid, p.13. With paper cheap and plentiful, the translation of Greek, Indian, and Persian scientific and philosophical texts underwent a renaissance between 800 and 1000, after which the Muslim world possessed an incomparably finer library of the ancients than was available in Latin. Ibid.

[62] The hierarchy of knowledge adopted and developed by many Muslim philosophers from al-Kindi in the third/ ninth century to Shah Waliallah of Delhi in the twelfth/ eighteenth century, constitute the mainframe of the Islamic philosophy and Islamic sciences. According to Seyyed Hossein Nasr, the primary motive behind this whole intellectual enterprise appears to be the concern with the means of preserving the hierarchy of the sciences and with the delineation of the scope and position of each science within the total scheme of knowledge. Seyyed Hossein Nasr, *Science and Civilisation in Islam*, (Harvard University, Cambridge, 1968), p.95. A recent profound

Science and technology were brought closer to each other in the Muslims tradition of knowledge. More than the Greeks or Romans, or their heirs, the Byzantine, but perhaps less than the contemporary Chinese, the Arabs recognised technology as a legitimate branch of science. A suggestion why this was so pointed to the influence of the Muslims' doctrine emphasising religious "theory and practice." The latter evidently was translated into the attitude of integrating the theory and practice of science. In fact, this constituted an important aspect of their modification of the Greek sciences. They took the theoretical science of the Greeks, and transformed them into a practical science. In other words, in this process of transformation, Muslims were able to create a distinct science infused with Islamic values. The Muslims paved the way for the modern relationship of science and technology that was totally different from the practice of earlier civilisations.

Europe became an heir to the corpus of Islamic learning after the decline of medieval Islamic civilisation. Throughout the Renaissance period, European science was more an extension of the Muslim science. The characteristics of the contemporary science was noted by many, including Stock who wrote that "throughout the Middle Ages, theory and practice, in science as in law and theology, were closer to the realm of everyday reality than they are today."[63]

A perceptible change was noted with the rise of the Cartesian philosophy

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study of this hierarchy of the sciences has been done by Professor Osman Bakar a prominent philosophical figure from Malaysia. He discusses, in detail, the basis of the hierarchy of the sciences that includes the methodological, ontological and ethical basis of the hierarchy of knowledge. Osman Bakar, *The Classification of Knowledge in Islam: A Study in Islamic Philosophy of Science* , (Kuala Lumpur: Institute for Policy Research, 1992).

[63] Ibid.

of science. The latter was rooted in the writings of Rene Decartes (1596-1650). He was responsible for establishing a new meta-science based on human consciousness and experience, ranging from the direct mental apprehension of God to observation and experiment in the physical world.[64] He provided the intellectual will and justification for contemporary European scholars to turn away from the medieval science of Greco-Islamic tradition.

Decartes advocated reductionism holding that physics was reducible to mechanics, and even considered the human body could be reduced to a mechanical contraption. He was equally famous for his doctrine of dualism, advocating the sharp distinction between soul and body, mind and matter.[65] But as Stock noted, even then "[the] fundamental Cartesian assumption of modern science - 'the cleavage between the world as it presents itself in the perceptual experience of everyday life and the world as it is in scientific truth and 'in reality' - was never framed in terms of rigid opposites."[66]

It is important to point out that, one of the reasons for the rise and development of science in the seventeenth century was the great emphasis on the use of mathematics. It was believed that proper insight of nature and could be understood by looking at the inherent mathematical regularities. This was evident in the work of Galileo, who studied the movement of the bodies, and applied mathematical analysis to formulate a mathematical description of the motion of bodies (to make a full measurement of the falling bodies)".[67]

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[64] W.C.Dampier, *A History Of Science: and its relation with Philosophy and Religion*, (Cambridge: Cambridge University Press, 1966), pp.134-135.
[65] Ibid, pp.135-146.
[66] Ibid.
[67] J.D. Bernal, 1957, p.259.

The Galilean approach to understanding of nature mathematically differs considerably from the medieval approach or the Muslims. For example, for the latter the functions of mathematical sciences were to discover an aspect of the real."[68] And the Muslim mathematicians universalised this and made it a principle of all sciences to seek knowledge of the domain of reality .[69]

However, Enlightenment, particularly the Galilean-Cartesian approach to mathematics resulted into the creation of a 'selective approach', in which a quality would be defined or redefined in quantitative terms in order to make it measurable.[70] This resulted into "a quantitative tendency which seeks as an ideal the reduction of all quality and all that is essential in the metaphysical sense to the material and substantial."[71] Galileo, for example, reduced all qualities (size, shape, quantity and motion) to that which could be dealt with mathematically. All other qualities like taste, smells, colours, with regard to the object in which they appear to reside are nothing more than mere names."[72]

Robert Boyle (1627-1691), a contemporary of Galileo advanced the idea and give the reason for the separation of qualities. To him what appears to be a qualitative difference between substances, such as colour, heat or texture, were in fact due to the mechanical action of particles.[73] In addition, for Boyle the contention that mathematical and mechanical principles are the 'alphabet in which God wrote the world', is a conclusion justified for the most part undeniable fact of

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[68] Seyyed Hossein Nasr, *Man and Nature: The Spiritual Crisis of Modern Man*, (Malaysia: Kuala Lumpur: Foundation for Traditional Studies, 1976), p.25.
[69] Ibid,p.25.
[70] Charles Boyle, *People, Science and Technology: a guide to advanced industrial society*, (Brighton: Wheatsheaf. 1984), p.217
[71] Seyyed Hossein Nasr, 1976, p.21.
[72] J.D. Bernal, 1957, p.297.

the successful explanation of things through the use of the quantitative principles.[74]

The major development that took place after the seventeenth century was then formulated into a philosophy of science rooted in Logical Positivism/Logical Empiricism doctrines of science.[75] Logical positivism is the extension and a modified version of 'empiricism', which argues that all knowledge is acquired through experience.[76] In the empiricist methodology, knowledge is not innate, it is observed and all ideas come from sensation or reflection[77]

According to logical positivism, philosophy and science are two distinct and differentiated domains. Since there are only two kinds of cognitively meaningful assertions; those of logic and mathematics, on the one hand, and those of the empirical sciences on the other. According to the first assertion, philosophy of science did not make any kind of empirical assertions, but rather its propositions were reducible to those of logic and mathematics. Thus on this view, philosophy of science was concerned exclusively with logical analysis. As Carnap

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[73] Hugh Kearney, *Science and Change*, (New York: McGraw-Hill Book Company, 1981), p.171.
[74] Edwin Arthur Burtt, *The Metaphysical Foundation of Modern Physical Science*, (New York: The Humanities Press Inc. 1951), p.166.
[75] How to distinguish these philosophical positions is difficult to determine but nothing of any importance seems to depend upon it. Richard F. Kitchener, "Towards a Critical Philosophy of Science", David Lamb, ed., *New Horizons in the Philosophy of Science*, (Avebury: Ashgate Publishing Limited, 1992), p.5 & 20.
[76] Stephen Priest, *The British Empiricists: A Critical Introduction to the leading Thinkers and key Ideas of the British philosophical tradition From Hobbes to Ayer* , (Britain: Penguin Books,1990), p.53. Science on the other hand, in the empiricist tradition, is based on the assumption that scientific knowledge can only be valid that is gained through the senses and experiments. Which is peculiar to a particular age and may change in another age. It is relative and its statements must affirm only what is observed and confirmed by scientists. Things that pertain to domains beyond the empirical spheres of experience are excluded and social forces are irrelevant to this science. Syed Muhammad Naquib Al-Attas, *Islam and the Philosophy of Science*, (Perpustakan Negara Malaysia, 1989), extract from pp.4-5.
[77] John Locke, *An Essay Concerning Human Understanding*, Peter H. Nidditch, ed.,), book 1., (Oxford: Clareodon Press, 1989), p.47.

asserted, " that philosophy of science deals with the logical analysis of the concepts, propositions, proofs, theories of science, as well as...its...methods."[78]

As a result, philosophy of science, according to this view was, imagined to be an activity carried out according to logical methods and judged by criteria of a purely logical kind. According to which, the philosophical correctness of a preferred philosophical analysis of, say, some scientific concept was not to be evaluated by reference to actual scientific practice or its history, but by reference to its explications.[79]

The status of the metaphysics and ethics in logical positivism has always been somewhat unclear. On the one hand, metaphysics and ethics were declared to be cognitively meaningless. As in the words of Carnap; "in the domain of metaphysics including all philosophy of value and normative theory, logical analysis yields the negative results that the alleged statements in this domain are entirely meaningless."[80] As such, metaphysical statements did not belong to science or philosophy of science, since science included only what was cognitively meaningful.

Ethics, insofar as it is interpreted in a non-naturalistic way, is cognitively meaningless according to the logical positivists. Ethical assertions make no claims to be true; they make no claims about what is the case; they are not rationally justifiable. On all these accounts they are opposed to factual statements. Facts and

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[78] Rudolph Carnap, "On the Character of Philosophical Problems", *Philosophy of Science*, No.1. 1934, pp.5-19.
[79] Hans Reichenbach, *Experience and Predictions* , (Chicago: University Chicago Press, 1938),p.6.
[80] Rudolph Carnap, "The Elimination of Metaphysics through logical Analysis of the Language", in *Logical Positivism*, A.J. Ayer, ed., (Glencoe, IL: Free Press, 1957),pp.60-61.

values are thus radically different for the positivist and one ought never to commit the naturalistic fallacy of moving from an 'is' to an 'ought'.[81]

A concern of philosophy of science, which Kitchener had suggested, should include the understanding of science philosophically, since anything that can help to do this should be ultimately useful in practical terms. In particular, philosophical analysis of science need to be checked against science in practice, since a constraint on any adequate philosophy of science is that it matches actual cases of science at their paradigmatic best.[82]

Philosophy of science should seek a more proper role of metaphysics. The latter must be sufficiently broad to include synthetic as well as analytic metaphysics. Up to now this has been missing from the mainstream of philosophy of science but it is a direction in which a more critical science of philosophy ought to go in order to be both epistemologically and sociologically useful.

Conclusion

Throughout the centuries, S&T have manifested in different forms. The diversity of interpretations has given rise to complexity and, to some extent, contributed to the contemporary confusion among scientists and engineers as regard to the nature of the S&T.

As was discussed in this chapter, the different meanings of S&T and the variety of philosophical theories of science, are grounds for our concern about the theories and meanings of S&T, and the extent which the latter influence in the

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[81] Ibid.
[82] Richard F. Kitchener, p.7.

formulation of S&T policy. Perhaps none other aspect of social policy could equal the potential impact that an S&T policy would have. It is therefore both an intellectual and a moral imperative for the policy makers to formulate their policy guidelines based on an epistemologically correct understanding of the S&T. The latter includes the kind of understanding that would give a balanced view of nature and takes also into account the impact of S&T on social and moral transformation of the society. The following discussion in the next chapter focuses on the impact of S&T on the society and social institutions.