Technology and Dialectics

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The industrial revolution was defined by the phenomenon of the application of systematically acquired knowledge (of thermodynamics) to the improvement of production methods (the steam engine). The implications of this lay, decisively, in opening the area of knowledge of production methods, in general, to human enquiry. This was given the (refurbished) name of technology, and accorded a central role in the dialectics of capitalism. Later, the 1931 International Conference on the History of Science and Technology formulated key ideas in the dialectics of technology. This groundwork laid the basis for substantial advances in the history of technology in the subsequent years.

However, inadequate theoretical elaboration of the institutional forms in which technological knowledge is commercialised has created the space for the growth of arcane theories of technology, which attribute to it a malignant agency. The emotive appeal of these theories is indicative of the reality: the results of the post-1945 scientific and technological revolution are expressed in forms structured by a transnational-dominated world economy.

I
Introduction

ECONOMICS is virtually unique amongst the social sciences in its long-standing interest in analysing the nature and causes of technological change. Adam Smith in the 18th century was followed by Andrew Ure, Charles Babbage and, of course, Marx and Schumpeter in the 19th and 20th centuries. However, most of the contributions by economists of a more contemporary period are not particularly relevant to the study of technology as a specific social science.[1] The reason for this is that the primary concern of recent economic theorising is with the role of technology in the process of economic growth, which is itself defined in increasingly more rigorous terms. While this is obviously a positive feature, it is an accompanying methodological concern that limits the discussion of technological issues. This is the presumption that the major concern in theorising is with the nature of competition in the market which would best promote economic growth. It is the assumption that it is necessarily competition between discrete entities (the firm), and that too, through the mechanism of the market, that advances technological knowledge that is the really limiting feature (or more precisely the ideological element) of most of the work undertaken by economists in the field..

Until relatively recently, of course, the specific nature of the way in which technology was conceptualised in economic literature was not really of concern. This was largely because issues of economic growth were the only channel through which technology impressed itself on the public consciousness. It was only with the evolution of the 'general student of technology' that there arose the need for a concept of technology as an entity with its own dialectics. This led to the recognition of the (necessarily) partial characterisation of technology within economic literature.

A major impetus to the study of technology came from the effects of the major technological developments of the last 50 years which have been identified as markers of the scientific and technological revolution.[2] The development of processes for the controlled release of nuclear energy, the possibility of major human organ transplants, the introduction of birth control mechanisms and the development of electronics form one aspect of this era. However, it has coincided with the appearance of the atomic and hydrogen bomb, the criminal introduction of imperfectly tested drugs such as thalidomide, and the prevalence of a series of disasters such as plane crashes, dam bursts and nuclear blowups which has even led to the sardonic characterisation of this era as associated with 'normal accidents'.[3] These events have given fresh life to the growth of artifactist thought – a line of philosophical reasoning that argues that the disasters sometimes associated with the use of modern technological artifacts are caused by the very nature of the technological processes themselves.

In one of its most recent formulations, the artifactist line of reasoning would distinguish between the implications for society between the handtools of the handicrafts era and the machines of subsequent eras as follows: because they are dependent on human users for both their source of movement and for guidance in their action, handtools have a unique relationship and dependency on human beings. To the extent that machines become independent, not only of human energy sources, but also of a human directing agency (as with automation) they begin to achieve a degree of autonomy.[4] Further, because machines concentrate increasingly greater quantum of energy in the hands of users, they necessarily introduce inequalities into the social order that would otherwise not be present. According to this line of reasoning, the person who owns a machine has more power than one who does not. Power is thus seen to grow out of the structure of the tool or machine rather than from the social organisation.

Leading on from this argument is the proposition that technology can become autonomous in relation to human users (even if not to its manufacturers). Different kinds of technology can have inherent features that generate quite distinctive impacts on societal orders. Most crucially, this is true independent of the social context within which some particular technology might be embedded or the particular social process it is associated with.

One of the major reasons for the growth and social acceptability of this line of reasoning has lain in the frightening attempts by some proponents of technology to promote technological solutions to societal crisis even before the problem has been decomposed into its socio-cultural (and political) and technological components. This is a manifestation of the propagation of a technological philosophy of technology (and society). This attempts, as did mechanistic philosophies of science with the emerging social sciences of the 19th century, to represent technological reasoning as a superior mode of thought to all others.[5]

It is for these reasons that renewed concern must be generated for views of technology which, while grounding themselves in a concrete analysis of the present situation, provide a direction by which this situation may be transcended. It is quite clear that such a path cannot be located within a trajectory of technological transformation alone: however, it is equally clear that it requires a conception of technology and its relationship to society which will permit such a transformation, i e, both a dialectics of technology and a dialectics of technology and society.

II
Technology as an Object of Enquiry

With the scientific revolution of the 16th and 17th centuries, the idea that science was not a hard-and-fast system of knowledge, but rather a system in constant flux (and that this could more accurately be called a process of knowledge acquisition) became generally accepted. In fact, without this change there could not have developed a distinct branch of knowledge now characterised as the history of science.[6] Simultaneously, with the dramatic challenge which Keppler's and Copernicus' theories posed to the church, came the recognition that science was a special kind of knowledge. The philosophical basis of this knowledge, expressed through both ideas and theories, came to be characterised as positivism, based as it was on extensions to Newtonian mechanics. Modern theories of dialectics may be seen to be the result of the development of the philosophy of science. Philosophy, of course, is engaged with science both in terms of the theories of science and theories about science. On the other hand, scientific theories and their associated ideas began quite early to influence visions of both the natural order and that of human societies: to the extent that philosophy implies a world view, scientific thought constitutes an implicit philosophy. However, in its primary sense philosophy of science is concerned with the nature of ideas and theories about science. It is well accepted that questions such as the nature of science, the meaning of science and the concept of truth in science are all important issues in the philosophy of science.

Because technology is usually understood to mean the act of making and using tools, and later, machines, the relationship between technology and ideas is not as easily apparent as that between science and ideas. Often, when ideas are at all associated with technology, they are seen to be scientific ideas used in a practical context.[7] This is a long distance away from, and also an indication of the very limited progress made in the 160 years since Babbage laid down the intellectual possibilities of technological enquiry:[8]

> ...:the arrangements which ought to regulate the interior economy of a manufactory are founded on principles of deeper root than may have been supposed, and are capable of being usefully employed in preparing the road to some of the sublimest investigations of the human mind.

Much earlier, of course, Bacon had argued that traditional philosophy had done less to change the world than had the invention of gun powder, printing and the compass. Philosophy (especially natural philosophy) should thus change its focus of concern and should became allied with the process of manufacture of tools.[9]

The 17th century scientific revolution is, of course, synonymous with the disjuncture with the ancient idea of science, which saw its role to be the explanation of directly perceived reality.[10] Further, experimental science defined itself, by contrast with Aristotelian thought, by postulating the application of geometrical and mechanical laws to nature. This was in opposition to efforts at the development of purely an intellectual vision of realities beyond the tangible world.[11] More importantly, it established the sphere of production as a legitimate area for the application of reason. Thus defined, technological 'thought' arises when the scientific revolution recognises and requires the incorporation of the analysis of the sphere of production techniques to further its own development.

This was the beginning of the era of technological thought but not yet of technology.[12] A much longer period was necessary, in fact several centuries before this interaction between science and productive technique could be put into practice. On the one hand, Bacon's idea of combining the resourcefulness of scientists, craftspeople and entrepreneurs in the better production of commodities granted a legitimacy and power to technical knowledge which existing societies were not prepared to admit. On the other hand, and more decisively, those very societies had not developed the economic forms of organisation within which the application of science to production methods would bring about decisive (economic) advantage. A technical culture was still only perceived as in the nature of a promise, without its own institutions and professional practitioners capable of influencing the economic and social organisation of the world.

In the English speaking world, the word technology has come to mean the specialised knowledge associated with production in all historical eras, and techniques to the skills and methods associated with production (or even with cultural and social activities such as swimming and dancing). On the European continent, in contrast, technique denotes all activities associated with production while technology is specific to the more advanced methods. Technology embodies accumulated knowledge, labour power and skills which owe their effectiveness to the use of tools for a long historical period. However a qualitatively new dimension is added by the way technology interrelates with science, and to the industrial system, to develop and achieve results.

Artifactist thought, of course, would claim that human societies have always been technological in nature, initially creators of tools, and then of machines. However, this transposition of the modern meaning of technology to cover production techniques which originated before the scientific revolution, essentially ignores the radical changes brought about by the growing connection between science and production from the mid-19th century onwards. This is in no way to ignore the historical evidence that in the pre-machine age, production methods could be systematised by formalising intuitive skills, the process of trial-and-error learning, to non-theoretical tools or maxims, and to some extent to articulate skill in descriptive mathematical forms. The change which gave technology its modern sense was the development of the strictly technological disciplines, of the strictly scientific production techniques, and the introduction of a body of professionals, engineers, technologists and managers. Parenthetically, it may also be noted that there exists in the heritage of philosophic thought, at least an implicit philosophy of pre-machine age production methods which implies the fundamental distinction between the production knowledge system of that period and of technology.[13]

Technology thus dates from the era of mechanisation, the industrial revolution, professional training for engineers and the ever-closer integration of science and production methods.[14] The first two conditions were met by the end of the 18th century, the third came in the 19th century, while the fourth, begun in the 19th century, was completed in the form of the scientific and technological revolution in the mid-20th century. In its most developed form, technology implies the existence of both the factory and the laboratory in a systematic relationship.[15]

It is significant that the word technology was given its modern meaning and came into general usage in the 20th century when handicraft production had been decisively replaced by machine-based production, and with economic processes both creating new branches of industry and large sale expansion of the older branches. This process of mechanisation raised the issue of technological dynamism in a political and economic context and led, eventually, to the concern shown by economists with the nexus between technology and economic growth, noted at the beginning of this paper.

III
Technology as an Area of Enquiry

The delineation of an area of enquiry denoted by technological thought arose, as has been noted, at almost the same time as that of the new scientific thought. However, the major impetus to the general study of technology came almost three centuries later, with the Soviet delegation's intervention in the 1931 International Congress for the History of Science and Technology in London.[16] The most celebrated of the papers, by B Hessen dealt with the social and economic context of Newton's Principia. Although the paper was concerned with a period predating the industrial revolution, the vital link with modern concerns lay in the methodological innovation based on the way it formulated the relationship between the world of science and the techniques of navigation, of ship-building methods and of propulsion problems, all of which grew directly out of the contemporary political economy.[17]

Implicit in Hessen's analysis were three components to an adequate conception of technology: the 'technological history of technology' (or more accurately, the dialectics of technology), the relationship both between science and the process of technological change and the role of technological innovation in presenting problems promoting scientific advance; and, finally, the relationship between the technological area of inquiry and other social and cultural institutions and activities.[18] It needs to be emphasised that the dialectics of technology, or the logic specific to the evolution of technology is quite distinct to the logic of socio-economic history.

Although these logics are quite distinct, their relationship has also a dialectical nature. Engels had, in fact, demonstrated this with his analysis of the industrial revolution. Technologically this event was defined by the initiation of the interaction between science and production methods, personified by the innovation of the steam engine. Equally, the methodological perils of disassociating the technological dialectic from social and economic history can clearly be seen in the subsequent trajectory of the concept of the industrial revolution. Popularised by the series of lectures given by Arnold Toynbee, it was subsequently enmeshed in controversies about whether the industrial revolution was, in fact, a mark of any significant socio-economic or cultural change (the postulated domain of historical enquiry); or even granting the validity of the technological aspect of history, about which specific element of the new machine-based production system it is which is paramount in defining the industrial revolution.[19]

These, however, are arguments of detail. Technologically, the industrial revolution had as its basis, the transition from the tool used by the handicrafts-based production system to the three element system of a machine (the prime mover, the transmission mechanism and the tool). Subsequent changes in one element of the machine, the tool, either through increases in its individual size, or in the number it was proposed to operate simultaneously, brought about a contradiction with the prevailing forms of motive mechanisms (wind, water and animal or human effort). The search for a more powerful and stable source of motive power led to the development of the steam engine. The complex of large-scale machine production based on steam, which continued up to the 1880s and 1890s defined an historical era with some specific characteristics.[20]

Generally there was a specific process for a given product. The differentiation and specialisation of productive processes had progressed very little. This, in turn, meant that there were few variations in the forms of organisation and management of production. Mass production, based on the use of interchangeable parts was almost completely absent and so were practices of technological process control and the use of measuring tools. The job content of workers was differentiated only by the specific industry they worked in. Within an industry, this differentiation was determined by the character of the work process, such as spinning, weaving and finishing in textiles. Even the range of skills required to service machinery was limited by the small degree of functional specialisation of the machinery. In fact, the controversy over the specific date when the industrial revolution can be said to have taken place is due precisely to the fact that at this stage the diffusion of science induced machines was actually confined to the area of mechanical forms of power for the major processes, and to some extent with metal working procedures on machine manufacture itself. Finally, although the trend of improving machinery through the application of science was developing, the aim of scientific research was generally inclined towards the explanation of natural phenomena and had little impact in machine production.

Although the key shift, both historically and logically, is in terms of the transition from production technique to technology in knowledge systems, and from tools to machines in the associated production systems, the dialectics of technology obviously lead to still further changes.[21] As the machine becomes increasingly independent of human or natural energy input, its character as an object undergoes critical transformations. Thus, the replacement of steam engines by electric motors gave a new form to both the prime mover and to the transmission mechanism of the three element machine. This both allowed the much larger physical separation of the prime mover and tool, through the agency of a distinct electric motor for each tool, and the possibilities of individual variation in what were now machine systems, working at different speeds. More significantly (and this was based on advances in chemistry) was the transition to an entirely new form of machine. It was now no longer a static object but both the embodiment of, and the initiator of operations, or of special physical, chemical or electrical processes.[22]

The design and construction of such process engendering and process enclosing machines imply not only the fabrication of a physical object, but of a process. Simultaneously, as machines expand their scope from mechanical to chemical and electrical processes, and are then linked together into systems, they become characterisable as objectified processes. This development may also be seen from another angle. Historically, the machine had developed from wind and water powered energy transformers to batch processing production (first of textiles, but then of chemicals), machining and assembly operations (using machine tools), and finally, industrial assembly lines. There is a difference, for instance, between using machines to manufacture a number of discrete articles, even when such articles are identical, and the bulk manufacture of some product that is homogeneous and uniform throughout, whether made in separate batches or continuously. In the latter case, the machine that makes such processes possible is itself a process of a kind. It is these developments which make the specific branch of knowledge and expertise characterised as technology an objective process (or dynamic system) in itself. While pre-machine age production knowledge relied for guidance primarily on sensory-motor skills, technical maxims and descriptive laws, technology bases itself on all three but also, increasingly, on specific technological laws and theories which are made possible by modern science and which, in turn, lead to engineering design.

Amongst the reasons why the dialectics of technology has received little attention, let alone systematic investigation, is the difficulty in clearly mapping out the area specific to science and to technology. There is the still greater problem in determining the nature of the relationship between them which is made more complex by historical experience of the changing nature of this relationship. The view that technology is merely applied science and the associated methodological construct, the linear model of the innovative process has been effectively challenged.[23] However a more sophisticated understanding of the relationship is still to be developed. It may be recalled that the linear model represented technological change purely in terms of innovations. Secondly, these innovations resulted from a process closely dependent upon, and generated by, prior scientific research. It is ironic that this model may, in fact, have had its origins in the soundly dialectical proposition that the marker of the industrial revolution was the application of science to the development of machinery in the form of the steam engine.

During the entire period of the dominance of the steam engine as prime mover, which lasted up to the end of the 19th century, it may have been true that scientific ideas were employed to bring about improvements in productive machinery. The reason for this is the early development of the science of dynamics through Galileo and Newton.[24] However, with the development of processes in applied chemistry, and the industrial uses of electricity, the gap between the existing knowledge-base and the expertise required to construct economically viable production systems grew unacceptably large. Thus, although Perkin had succeeded (though accidentally) in the laboratory synthesis of mauve, the first of the aniline dyes, in 1856, the breakthrough was of little industrial consequence until the process could be scaled up for large-scale processing. However, the design and construction of such plants involves an entirely different set of activities and capabilities than those that generated the new chemical entities in the laboratory. First of all, the problems of mixing, heating and contaminant control, which can be carried out with great precision in the laboratory, are immensely more difficult to handle in large-scale operations, especially if high degrees of precision are required. Eventually, to manage the transition from test tubes to manufacture, where output has to be measured in tons rather than grams, an entirely new methodology, totally distinct from the science of chemistry had to be devised. This methodology used, as a central concept, the idea of unit operations, such as pulverising, heating, crystallising and so on, and signified the emergence of chemical engineering as a body of knowledge not reducible to applied chemistry.[25]

Further, with the growth of large-scale production, the institutional innovation of the industrial research laboratory has provided the means for the empirical observation of the reciprocal flow from technology to science. It has, in fact, been suggested that as an alternative to the commonly held view of contemporary high technology industries as those based on science, it can be suggested that industries at the technological frontier help to define the research agenda for science. This is particularly true when the high quality of scientific personnel in industrial laboratories makes them an acceptable peer group for scientists in academic institutes.

The methodological point to be made from this discussion is that the modern concept of technology originated in an historical event, the industrial revolution. Subsequently, the concept has evolved as both the industrial structure, and the institutions associated with this structure have changed. This evolution is historically linked, of course, with the developments in capitalism. A specific example of the latter lies in the heightened degree of transnational competition in the technologically advanced industries since the early and mid-1970s. The often remarked fact that Japanese investment in basic research, which is considerably less than in its major competitor countries, has not prevented Japanese pre-eminence in advanced technologies has, clearly, had an impact on the realisation of the complex character of the science-technology relationship.

Even within the specific area of the dialectics of technology, progress seems to have been less than could have been expected because of the lack of attention paid by social scientists to the 'engineering method'. Part of the problem, of course, lies in the specific activity of engineers, and therefore in the analysis of the method. Engineering as a profession is identified with the systematic knowledge of how to design useful artifacts or processes, a discipline that includes some science and mathematics, the engineering sciences such as strength of materials, thermodynamics and electronics. However, in a significant choice of words, a historian of chemical engineering notes that "Often, in dealing with a complicated practical situation, the engineer arbitrarily reduces the number of variables in [the] ... theory by combining them into dimensionless groups, of which a well known example is the Reynolds number characterising the flow of fluid through a pipe".[26] This implies that the actual activity of the technologist is distinct to the theoretical basis that underlies the documented knowledge system. It is then difficult to discern a pattern of consistent behaviour which would qualify as a distinctly technological sphere of knowledge. It is equally, if not more true however, that a failure to understand the concept of the technological sciences has prevented sufficient attention being paid to the data which are available for analysis.

IV
Scientific and Technological Revolution

As in the case of the industrial revolution of the 18th century, and the transformation brought about by the chemical-electrical innovations of the 19th century, the scientific and technological revolution represents a moment in all three of the components of technology mentioned earlier: the movements within technological knowledge itself, the relationship between this and the current phase of scientific knowledge, and the connections between technological enquiry and other fields of social and cultural activity. An elaboration of these moments will help in defining the scientific and technological revolution.

As far as the dialectics of technology are concerned, the qualitative feature which distinguishes the scientific and technological revolution from previous periods lies in the change in the principle which has, until recently, guided technological evolution. Usually this evolution is defined in terms of the degree of sophistication of the production mechanism; thus the era of handicraft techniques, then of manufacture and, later, of machine based production and automation. Alternatively, there is possible a periodisation based on the energy source, the era of manual labour (and wind and water power), the age of steam and that of electricity. However, the scientific and technological revolution encompasses a far wider range of phenomena than the energy base or the nature of the production mechanism. It is not merely another stage in technological evolution but stands in contrast to all earlier periods. This can be made clear if the distinguishing feature is correctly identified.

If the division into periods is based on the method of human interaction with the raw materials found in a natural form, then a unitary principle can be seen to underlie the technological developments of all preceding eras. The increasing sophistication in the use of the principle, in fact, defines a very long cycle of development and generates a common content and logic of evolution. The principle is, of course, that of the mechanical processing of materials. Technological progress during this entire cycle was primarily concerned with addressing the problem of more efficient ways of mechanical processing.

Thus irrespective of the tools or machinery used in this period, in the transition from manual to mechanised forms of production, the laws of the mechanical world were the guiding principle. Within this framework, all earlier periods, in spite of the great differences in the character of the instruments used had a unifying feature, in terms of the principle on which they interacted with nature. In fact, J D Bernal has argued that even in the era of manual production, solutions to most mechanical and technical problems in the processing and combination of materials had been identified. Subsequent developments have used these solutions as the basis for more efficient methods of (mechanical) processing.

There is another way in which the uniformity of the cycle of technical development may be traced. This lies in the nature of the energy transformation process: the ultimate objective of using all the sources of energy which had been developed was for the transformation into mechanical forms of energy. Even the initial development of automation was towards improving the continuity of a production process based on mechanical principles.

Under these conditions, technological development implied an increase in the capital-output ratio. Industrial progress was associated with enormous expenditure on production machinery, natural resources and in the demand for highly trained and qualified workers. These requirements arose out of the principle (or paradigm) of mechanical processing because, within the logic of this principle, technological advance may take place but the principle itself cannot be modified or changed.

The period of development of the mechanical processing of natural materials covered a very long period during which the potential of the principle was fully realised. In one respect, however, the previous era did lay the foundations for the subsequent scientific and technological revolution. This was, as has been noted, the development of automation, which has removed the necessity of human participation in the 'mechanical' aspects of production. Precisely as the development of automatic devices is bringing the era of mechanical processing to an end, principles of automation are providing the basis for the 'machineless' stage of production of the new technological era.[27]

This type of production is concretised in the metallurgical and petro-chemical industries where there is certainly a raw material, but no machinery in the accepted sense of the word. Rather, the end-product is obtained by the systematic subjection of the raw material to pressure and temperature changes, often with the use of catalysts. The parameters under which the process operates successfully (and safely) are so many in number and interconnected that, without automation, it would be impossible to operate them at all.

The second manifestation of the scientific and technological revolution lies in qualitatively new features in the science-technology relationship. Although the application of scientific knowledge to the development of the steam engine is a concrete manifestation of the principle of the industrial revolution, science and technology largely continued to develop on parallel lines. Although they intersected and interacted with each other, their progress was not organically linked. In the second half of the 20th century, the interconnection between the two intensified dramatically and it then became possible to speak of 'scientific and technological progress'. This integration created a system and thus an object of enquiry in itself.

Although scientific and technological progress has emerged as a system or a process, technological development continues to take place to a substantial extent on the basis of purely empirical enquiry. As the productive apparatus operates, practical problems arise and require solution even if the scientific basis is not yet available. In other words, not all varieties of industrial technology are equally open, as yet, to scientific analysis. By and large, the more complex the basis of the technology, the greater is the time required for its development or for its restructuring on a scientific basis. Seen in these terms, the scientific and technological revolution marks the beginning of the period in which more complex processes (electronic and biological) form the basis of production.

Although it is these developments in productive technology which set the most challenging tasks for science, in fact all varieties of technological change present new scientific problems. Apart from the revolutionary innovations, there are also changes in the generation of a technology where the fundamental scientific principle remains unchanged and, of course, incremental changes in one or more characteristics of a given generation of technology.

It is, of course, a matter of definition that the science-technology interactions are most significant in the so-called high technology industries. But it must also be recognised, to begin with, that there still remain crucial portions of high technology industries where attempts to advance the technological frontier are painstakingly slow and expensive, because of the limited guidance that science is capable of providing.

If science could provide a logical predictive base for moving to optimal design configurations, development costs (which account for about two-thirds of the R and D expenditure in the US) would not be such a high proportion of technology development expenditure. The reason why they are so high is because engineers and product designers continue to need to engage in very extensive testing activities before they can be sufficiently confident in the performance characteristics of a new product.

The interaction between science, technology and production began with the industrial revolution, gathered momentum with the developments in chemical technology and the continuous processing industries, and has reached a highpoint with the scientific and technological revolution. Such a method of placing this revolution in its historical context is a starting point towards its characterisation, but there is also a need to identify the nature of the processes underway within both science and technology.

The specific features of present day science lie in the addition, or at least greater importance, given to lines of enquiry which until recently formed a minor aspect of the scientist's work. While continuing with the object of refining the analysis and explanation of the natural world, the sphere of operation of science is now increasingly weighted towards synthesis, and to the elaboration of control as a process in itself. In more concrete terms, the qualitative dimension is provided by the combination of analysis and explanation with fundamentally different processes. These include controlled intervention in the structure of materials, the synthesis of substances with specific, predetermined, properties, the development and control of nuclear fusion and fission reactions, the elaboration of theories of information and control and, finally, intervention in organic processes (the basis of biotechnology).

The third area of enquiry relevant to the study of technology is the interaction between other spheres of cultural and social activity and the productive system. It is here that there has been the greatest failure to develop the dialectics of technology appropriate to the era of the scientific and technological revolution. As has been mentioned at the beginning of this paper, the urgency of the attempt to identify an adequate conceptual basis for technology itself arises from the social and cultural effects of this revolution. However, this is clearly insufficient in itself. What is required is also a methodology to address the issues of the effects of advanced technologies on society and culture which has been heightened by a series of accidents with tragic consequences, mentioned at the beginning of this paper.

Concretely, this would imply the development of detailed case studies of the considerations underlying the commercialisation of the research and development efforts within transnational corporations. Currently, this is the major source through which new technologies impinge on the public consciousness. Included within the ambit of the research would be the process of appropriation by these corporations of many new ideas which originate elsewhere, and the marketing efforts aimed at the creation of new consumer desires, which may be marginally related to the actual potential of a new technology. It seems that unless this area is addressed, questions of the absence of any ethical basis for the adoption of some new technologies, the impossibility of effecting democratic control over the direction in which some others are evolving, and so on, are going to lead to impasses. The end result may well be a series of diversions from the more substantive movement forward which Bagrit saw as the ultimate advantage of the age of automation.

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Notes

1 For Marx's contribution, see Rosenberg (1976). All the references mentioned by Freeman(1994) are, in his own words, neo-Schumpeterian in inspiration. van den Belt and Rip (1987) also suggest that the renewed interest in Schumperterian methodology may provide the basis for such a social science analysis.

2 The concept was probably used for the first time by Bernal. It is clear that Bagrit (1966) was referring to the same phenomenon in the discussion of the "Age of Automation". The social and cultural effects of the revolution in the western world form the basis for David Harvey's analysis of the 'Condition of Post-Modernity' (1990).

3 Mitcham (1994) has a food-for-thought provoking chronology of the dual aspects of the effects of the Scientific and Technological Revolution.

4 Although artefactist thought does not formally define the concept of a machine, its line of argument is consistent with the accepted definition that the machine, at least in its earlier phases was characterised by three elements: the power source or motive mechanism, the transmission mechanism and the tool. It is important to note that the motive mechanism can be provided by human, animal or natural agency. Machines can thus be dated from the era of wind and water mills, handlooms, and simple harvesting devices.

5 Although Dr Strangelove exemplifies the approach in its most alarming form, this philosophical basis underlies the development plans introduced in the postwar era in third world countries, in state-led attempts at 'technological transformation'. Anchiskin (1987) refers to the tendency as a form of neo-positivism (pp 195-200). Mitcham (1994) sees it as the attempt by 'Engineering Philosophy of Technology' to hegemonise the entire field of philosophical enquiry (pp 19-93). See, also, Ilyenkov (1982).

6 Kedrov (1977) discusses the criteria defining a scientific revolution in some detail. The evolution of science is considered in ways germane to the concerns of this paper by both Mikulinsky (1977) and Salomon (1990).

7 This is, of course, the basis of the linear model of basic science-applied science-technology. For the effects, on the technology base, of state policy resting on the very simplest version of this model in India, see Parthasarathi (1987).

8 Quoted in Rosenberg (1994), p 24.

9 Perhaps because he has been influenced by his own chronology of the disasters associated with the second half of the 20th century, Mitcham (1994) feels that "... practical efficacy in changing the world is not the highest or most inclusive criterion of judgment. When someone wants to bring about practical change, it always makes sense to ask why or for what?" (p 140).

10 In other words, the underlying premise earlier was that the object of scientific enquiry was that which was tangible or seemed perceptible. For a detailed discussion, see Kedrov (1977), pp 52-54.

11 Koyre (1989) has an interesting discussion on Galileo's ambivalence towards Plato's view of science.

12 The distinction between 'technological thought' and 'technology' and the discussion in the following paragraphs is developed from Salomon (1990).

13 Mitcham deals with the western tradition (pp 117-34).

14 In addition to the replacement of tools by machines, the process of mechanisation also incorporates the diffusion of mechanisms (of which the clock is the outstanding example). The distinction between a machine and a mechanism is that the former is designed to perform work (in the sense that physics and mechanics recognise).

15 See Noble (1979) for a detailed account of the growth of corporate industrial research laboratories.

16 Although this claim is made by Mikulinsky (1977), it is given unexpected support by the admission by Redondi in his introduction to Bhattacharya and Redondi (1990). The papers were published under the title of Science at the Crossroads. See, also, Olwell (1996).

17 Hessen (1931).

18 These, it was noted by Daumas (1969), had been formulated by Lucien Febvre. Ironically, this was part of the effort by which Annales entered the field "... where other historical methods, notably Marxist historical materialism already seemed to be so firmly entrenched". (Pietro Redondi's introduction to Bhattacharya and Redondi (1990) p 7.

19 In otherwise important contributions to a dialectical conception of technology, Daumas (1969) raises the first issue (pp 222-25) while Salomon (1990) raises the second (pp 260-63).

20 This, and the succeeding paragraphs, are based on the discussion in Heinman (1981), pp 61-65.

21 This is a process defined by Heinman (1981) as "scientific and technological progress" (pp 17-34).

22 Detailed descriptions of these transformations are in Heinman (1981), pp 65-80 and Anchiskin (1987) pp 126-76. Mitcham (1994), pp 168-69 provides a much briefer, though conceptual, account of the same processes.

23 Nikolayev's (1975) entire monograph deals with this issue. See also, Rosenberg (1991) and Sheinin (1978), pp 74-122.

24 The two branches of dynamics, kinetics and kinematics deal, respectively, with the motion of rigid bodies abstracted from any external force, and with the effects of such forces on the motions of the elements of the machine. It may be noted that the ways in which the elements of the machine are interconnected defines its mechanism. The areas of knowledge germane to these issues form the basis of mechanical engineering.

25 See the Rosenberg reference in note 23 and, in particular, Landau and Rosenberg (1992).

26 Davies (1980) quoted in Rosenberg (1994), p 145, fn 6.

27 Kolantayev (1981); Bagrit (1966).

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