GOAL DIRECTION OF SCIENTIFIC RESEARCH

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1. Introduction

That science, both as an institution and a body of knowledge, is neither
invariant nor homogeneous is by now widely accepted. Thus Ravetz (1)
has argued that three distinct varieties of science have been historically
perceived and have been associated with particular interest groups:

(i) ‘Pure, academic science’ which was based on an ideology derived
from nineteenth-century German universities:

Here science is totally inward looking, its only offerings to the outside world are general
contributions to knowledge and culture, unpredictable technological applications, and the
example of its endeavour (2).

(ii) ‘Ideologically engaged science’, which is considered a bearer of truth
and reason, standing against dogma, superstition and oppression, and a
weapon in the struggle against a variety of material and spiritual ills:

By its very nature science could not produce either error or evil, and so it had a privileged
position among all sorts of ideologically engaged activities (3).

(iii) ‘Useful Science’ where ‘the results and methods of science are
applied directly to technical and practical problems; and those external
tasks provide stimuli, goals and partial justification for scientific work’ (4).

There is considerable evidence that it is the last of these which is most
appropriate as a description of contemporary ‘science’. Research has
become concentrated in industrial and government laboratories (5),
where the demands for profit and growth and accountability, respectively,
require that the research be directed, at least in the long term and more
often in the short term, to practical ends. Furthermore, it is directed primarily towards the general objectives of economic development and national security (6).

This orientation towards ‘useful science’ has had a considerable effect on the status and self-images of those engaged in scientific research, whether they call themselves scientists, research workers or technicians. The growth of unionisation among scientific workers (7), reflecting an increased awareness of their loss of status can be seen as a response to the directed nature of modern research. Furthermore, this direction is not restricted to the environment of government or industrial laboratories, as shown by the organisational constraints operating in ‘big science’ institutions such as CERN (8).

In spite of the evidence that research has become a much more highly controlled and directed activity, academic scientists and in particular the elite who represent the scientific community in negotiation with the paymasters and political interests, continue to project the image of science as autonomous and apolitical, concerned solely with the objective pursuit of truth, i.e., as ‘pure academic science’. A clear illustration of the solidarity with which this position is held is provided by the response of British scientists to the Rothschild reorganisation (9). Such a view can be considered a self-serving ideology, protecting the interests of scientists from external control (10):

The theory that scientists follow only the internal rules of science would seem to reinforce their efforts to prevent the subordination of their work to standards extrinsic to science and to protect themselves from external political influence (11).

We would wish to argue that the continuation of this misleading view of science represents a dangerous mystification which can serve only to obscure the role of science in modern society, confuse the scientist and science administrator, and alienate the public.

The extent to which this protective self-image has influenced the study of science and its institutions has been shown by the pervasiveness of the analytical dichotomy between ‘internalist’ and ‘externalist’ explanations which reinforces the notion of science as a social system separated from, but occasionally influenced by, other social forces (12). It is also evident in the concentration of studies on precisely that small sector which most
nearly approximates this model – that of academic, university-based, ‘pure’ research (13).

This disjunction between ‘pure’ and ‘useful’ models of science is reflected in the conceptual distinction between ‘pure’ and ‘applied’ science (14) which has provided the basis for most attempts to relate scientific knowledge to socio-economic objectives. In this model, certain ‘pure’ kinds of research involve the objective pursuit of truth, and should be conducted in entirely autonomous fashion, i.e., according to the regulatives of science only. Other ‘applied’ research is directed to the achievement of specific and practical objectives and may therefore be expected to be administered and held accountable, in more or less the same way as any other production or social function (15).

The establishment and subsequent growth of science policy, with its emphasis on mechanisms for evaluating claims for research support, and the form of institution most suitable to administer research funds, reflected a concern to more efficiently direct science to desired ends (16). However, once again the self-image of science appears to have been accepted:

The underlying model for science policy organisation is based on the transaction concept drawn from political science; its aim is the establishment of effective institutionalised transaction processes between an independent science institution and society, via society’s representatives in government. In this model there is no mechanism permitting society’s interest to operate on the scientific institution, and analysis, planning and one might add, responsibility, is limited to the areas of application of scientific knowledge (17).

Blume (18) has argued for the establishment of a political sociology of science directed towards the explanation of the contemporary politically directed, occupationally differentiated and institutionally disparate form of science, but as yet there has been little direct response to this challenge. There is, of course, a well established Marxist tradition of relating science to social needs which can be traced back to Hessen (19) and has included within its ranks such notables as J. D. Bernal (20) and Joseph Needham (21), but its major contemporary expression is in detailed historical studies of the way in which particular scientific theories reflect the socio-economic and cultural context (22).

One promising development has been the work of the project group ‘Alternativen in der Wissenschaft’ at the Max-Planck-Institut, Starnberg,
and Weingart at Bielefeld, who have attempted to develop the concept of ‘finalisation’ to establish theoretically the conditions for effective direction of scientific knowledge towards politically determined goals (23). This approach has been developed over the past five years and in the most recent paper (24) takes the form of a sophisticated and fruitful model for the formation and transformation of research objectives, and the limitations placed on the achievement of such objectives by the state of development of relevant knowledge fields.

However, although the supporting case studies consider a range of specialties (25), we wish to argue that ‘finalisation’ represents only one extreme, and rather unusual type of externally directed science, taking as its implicit model the U.S. crash programmes to land a man on the moon (the Apollo project) and to find a cure for cancer (the ‘cancer moonshot’). There may be a very wide spectrum of goal-orientation within science, ranging from the directly politically motivated programme to a much more general and pervasive shaping of cognitive goals in accord with social or economic needs.

Thus there is a need to develop a more general analysis of the establishment and operation of goals both within the scientific community and between it and its paymasters. Such an analysis should take account of the fact that scientists are themselves involved in the process of goal formation, and that it is determined, at least in part, by the state of knowledge perceived or claimed to be relevant. Furthermore goals, at least at an operational level, may be in a state of continual transition and redefinition. Such an analysis of the function of goals in science is seen as part of a programme to develop a flexible theory of mediation between socio-economic and cognitive aspects of the social reality which constitutes and conditions science. Previous papers have explored the need for a contextual model of scientific development (26) and the roles of occupational and cognitive differentiation in shaping the knowledge structure (27).

2. The Common-Sense Notion of Goals for Scientific Research

All scientific work can be regarded as goal-directed, at least in the sense of Habermas (28) who argues that all work is ‘purposive rational action’, in
that it is either instrumental action, or rational choice, or their conjunction. Thus,

science is oriented towards goals which may be directly or indirectly perceived, which are expressed at varying levels of generality, which are developed and transformed by social processes and which are dynamically linked to scientific practice and the state of knowledge in such a way that the goals and science are only analytically separable (29).

However, the fact that all action is directed to goals would appear to have led students of science to treat goals as a common-sense phenomenon. As a consequence the ‘low-level’ goal of problem-solution has been the primary focus of investigation, and other levels or kinds of goals which may shape the research process have been neglected. Moreover, the existence of ‘problems’ has been taken for granted; in the positivist model of science, problems are posed by the external reality. It is only with the development of the post-Kuhnian sociology of scientific knowledge that the perception of a scientific problem has been considered in need of sociological explanation. Furthermore, the acceptance of goals as a common-sense phenomenon has entailed a common-sense relationship between goals and the means used in the attempts to realise them. Consequently the relationship between means and goals (or ends) has not been an issue in science studies. The dominant approach has been a functionalist analysis of the evolutionary movement of means towards ‘immaculately conceived’ goals.

The analysis of goals by sociologists, at least in the sense used in this paper, has in general been quite limited, with the marked exception of organisation theorists. Within this literature, there are a number of distinct traditions, including of relevance to this paper, studies of the range of goals pursued by industrial firms, the evolution of goals within organisations, and means of changing goals in normative institutions (30). We will draw on some of these concepts in subsequent arguments.

As already noted references to goals within science are in general sparse, or made, in passing, as part of a more general analysis. Thus Merton (31) sees the goal of science as ‘the rational pursuit of truth’. For Sklair (32), ‘the charter or purpose of science’ is of three types viz., the quest for knowledge for its own sake, for alleviating human suffering and satisfying the needs of mankind, or to provide an economically rewarding
career. Richter suggests:

The goal of science, as commonly recognised today, involves the acquisition of systematic, generalised knowledge concerning the natural world; knowledge which helps man to understand nature, to predict natural events and to control natural forces (33).

Ravetz has made a considerable effort to clarify the notion of goal by developing a hierarchy of 'final causes' that determines the goals of the research task. He distinguishes between goal, function and purpose:

the task itself has a goal, which is conditioned more or less strictly by the function which will be performed by the result of the accomplished task; and this in turn is governed by the ultimate human purposes which are expected to be served by the performance of that function (34).

The goal is the solution of the research problem.

The most detailed analysis of goal-direction in science is offered by Hagstrom (35) but in general the concept is used in a common-sense way to explain structural change, the role of fashion and the processes of disciplinary differentiation and social control. Thus, although Hagstrom observes that:

Segmentation begins with cultural change, the appearance of new goals in the scientific community. Of course, new goals do not spontaneously appear: scientists actively seek them (36),

he provides few indications of the origin of the goals and continues by examining the way scientists respond to cultural change once it has occurred. The uncritical use of the concept is highlighted by the conflation of 'goals' with 'problems'. Thus, the above quotation continues,

Those who discover important problems upon which few others are engaged are less likely to be anticipated and more likely to be rewarded with recognition (37).

Where do these goals come from, and how are they formed? Hagstrom, adhering to the internal/external demarcation, distinguishes between goals arising inside and outside science:
When the relative importance of goals is easily ascertained by generally accepted criteria, or when the goals are given by non-scientists, there will be little play of fashion. In many of the applied sciences, where the goals arise outside of science and the criteria of success are usually given by non-scientists, scientific fashion is perhaps least important. In the empirical sciences, especially those with a more or less rigorous theoretical framework, the goals arise within science, but in many respects they appear to be 'given' in the confrontation of theories by 'nature' (38).

The change of goals directed from within science is due primarily to the actions of leaders:

The orderly succession of goals in a discipline is the sum of individual responses to a situation being changed by discoveries. Changes in the goals of individuals are facilitated by the tendency of scientists both to seek social validation of their goals and to follow the lead of outstanding men . . . . The ease with which physicists can change the goals of their discipline is linked with the structure of leadership in the discipline. While the ease of determining the really important problems makes it easier to spot leaders, the existence of leaders facilitates the orderly succession of goals (39).

Hagstrom makes other distinctions between types of goals, but not in any systematic fashion. Thus goals may be 'short term', i.e., specific problems being researched (40), 'traditional' disciplinary goals, as for example the purely biological goal of understanding life as a function of the cell (41), 'applied goals' such as the pursuits of industrial and government laboratories (42) and motivational goals such as incentives, particularly recognition (43). Implicitly, all the objects of competition between individuals and organisations are treated as goals. For example, position, promotion, research facilities and graduate students are scarce resources to be competed for, i.e., goals to be achieved (44).

The recognition of different levels and types of goals represents a considerable advance, but by failing to distinguish between goals and problems, and even more by linking this analysis with Merton's (45) five ideal types of scientific performer Hagstrom is committed to a static analysis which cannot comprehend interpenetrating goals and means. More fundamentally the analysis of goals, in terms of purposes to be achieved, is hindered by the adoption of a functionalist stance, whereby goals and changes in them can be interpreted only in terms of maintenance of the institution and correspondence with the means for achieving them.
3. An Exposition of Goal-Direction in Scientific Research

Before proceeding further it is important to clarify the meaning to be applied to the concept of goal. It has been noted previously that this concept has not been rigorously developed, in part because almost any sequence of behaviour can be divided into segments of varying 'size', each of which can be said to be goal-directed:

Since there is only a relative distinction between means and ends, and since, therefore, any end or goal can be seen as a means to another goal, one is free to enter the hierarchy of means and ends at any point (46).

While precise semantic definition may be difficult, in this paper we will attempt to restrict the usage of the term goal to an over-arching objective or end which serves in part to direct one or more fields of research and of which individual, or groups of, scientists need not be explicitly aware.

It is important to recognise that we are not here considering the goal of 'science'. Along with Richter (47) we reject the notion that the concept of goal can be fruitfully applied to the whole enterprise of science. Recent developments within the sociology of scientific knowledge (48) emphasise the distinctive cognitive and social structure of different sciences. However, whether science is examined from a cognitive perspective, be it discipline, specialty or research area, or from an occupational standpoint, in industry, government or university, we would argue that the concept of goal can provide a very useful insight into the ways in which the modern sciences reflect and can be directed to the needs of industrialised society.

Furthermore the distinction that Ravetz (49) makes between goal and purpose can be accounted for, in that each scientist may structure his or her research in order to achieve particular individual purposes, but goals form an important, and so far unconsidered, element of the cognitive, and hence social, structure, which shape the possibilities of achieving particular purposes.

In this paper, a clear distinction is made between goals and research tasks or problems. It can be argued that much of the sociology of science has been directed to an examination of the cognitive and social means of achieving the low-level objective of problem solution. Considerable
progress has been made in explaining how cognitive and social structures, in part determined by the elite members of a research community (49a), shape the range of appropriate research tasks open to the ‘autonomous’ academic scientist. The way in which the apprentice, from student to post-doctoral fellow, is presented with a research ‘package’ which closely defines an appropriate set of research problems has been usefully explored by Whitley (50) and others. Less attention has been applied to the work of scientists in industrial and government environments, though here it is clear that the research tasks are equally prescribed, though in a more overtly hierarchical or bureaucratic manner and with a more immediate orientation to the objectives of the organisation. While studies of the research task are of undoubted value, we are concerned here with the extent to which high level goals form part of the structure determining these research tasks.

Particular goals may vary greatly in type, level of application and origin. The development of Kuhn’s models suggest that cognitive structures operate at different levels and thus it appears reasonable to infer that goals, which to a large extent will express themselves through the cognitive structures, may also operate at different levels. Using Whitley’s categorisation, at the highest level goals form part of the ‘metaphysical’ component of scientific knowledge – ‘the overall system of values and beliefs which serves to justify and integrate the scientific activity with other systems of production . . . and provides a general world view’ (51). Such high-level goals need not be consciously associated with all phases of scientific work; they may form part of a tacit background knowledge internalised through socialisation processes of which the scientist or administrator may be unaware. Nevertheless they may, in a highly mediated form, provide a powerful directing influence on scientific research. To illustrate, Mullins has identified the high level goal of the phage group as determining ‘the secret of life’ (52). On the basis of a detailed examination of solar energy research Jagtenberg has argued that the consensual high level goal has been “making the sun work for mankind by extracting large amounts of useful energy from solar radiation” (53).

Goals may also be formulated directly at the next level of cognitive structure, i.e., specialty concerns, described as: “the general problems or purposes of conducting the activity seen in terms of a particular definition
of reality which may incorporate a number of evaluative frameworks" (54). At this level goals may take a rather more concrete, and explicit form as, continuing the phage group example, the determination of "the mechanisms by which genetic information is transferred" (55). Other examples include plasma physics, where the goal is one of understanding the properties of plasma sufficiently to allow continued controlled fusion with a positive energy balance, or biotechnology, where the goal is the artificial mutation of microorganisms suitable for the manufacture of industrial products (56). Cognitive structures at lower levels, namely explanatory models, techniques and research practices, may contain expressions of the higher level goals but the latter are unlikely to operate directly at these levels.

Goals may also be of rather different types. Thus some goals may take the form of very highly mediated expressions of socio-economic and cultural context such as operate in physics and biology (57). At the other extreme goals may be much more direct expressions of non-scientific interest groups such as sectors of government, industry, or the public, as seen in the development and direction of fields such as computer science, geology, tribology, toxicology and environmental science. We emphatically reject the adherence to the internal/external dichotomy which leads van den Daele et al. (58) to restrict the concept of goal to an objective developed outside the scientific community. In accord with the view of scientific knowledge as the highly mediated expression of socio-economic as well as ontological constraints, the analysis of goal-direction should be sufficiently general to apply to all sciences.

The major argument of this paper is that all modern science can be understood as a goal-directed activity. That is, scientists and those concerned with directing and influencing research operate according to goals which are

(1) Established as the result of social and political processes which involve dynamic interaction between interest groups both involving and excluding direct scientific interests and which may be directly or indirectly perceived by scientists.

(2) Mediated by scientific, socio-economic and political considerations and expressed at varying levels of generality; (59) these mediated versions may be expressed within 'official' statements of research programmes or
they may be deeply embedded in the cognitive structure of the relevant sciences.

(3) Dynamically linked to an evolving body or bodies of scientific knowledge in such a way that goals and science are only analytically separable; both cognitive and social aspects of research are directed and constrained by orientation to goals which are posited and potentially continually redefinable in terms of changing theory, techniques and socio-economic conditions.

In summary, three characteristic features of the goal-direction of scientific research can be identified: goal establishment, goal mediation and goal evolution. It is important to recognise that these are only analytically distinct; it would be very unusual for them to follow each other as three distinct phases. In the subsequent sections we will examine these features and illustrate them with examples drawn from a number of case studies in order to assess the utility of the concept of goal-direction in science and to develop a model which provides the basis for a clearer and more practical understanding for both scientists and science administrators of the ways in which modern science is, and can be, directed.

4 Goal Establishment

Van den Daele et al. have pointed out with considerable clarity that the establishment of goals – or as they describe it, “the transformation of political into scientific goals” (60) – can involve a varying degree of determination by political and scientific authority. The establishment of goals for scientific research programmes have been thoroughly documented for such classic cases as the Manhattan Project (61), the Apollo Mission (62) and the U.S. Cancer Programme (63). However, below are presented studies of goal establishment in less spectacular and possibly more typical cases of goal-directed scientific research.

Tribology (64)

Concern with the problems of friction and the means of eradicating it is not new. The American Society of Lubrication Engineers was formed in
1944, and by 1954 the subject of lubrication engineering was being taught to undergraduates at Imperial College, London (65). However, Dowson (66) has argued that the industrial developments of the post-war period posed a series of qualitatively new questions for mechanical engineers. High speed rotating machinery, more severely loaded reciprocating machinery and hostile working environments were increasingly causing breakdown and failure in production hardware. In 1962, a special committee was set up by the U.K. Department of Scientific and Industrial Research (DSIR), under the chairmanship of Mr. G. B. R. Fielden to investigate 'the problem' of design within mechanical engineering. At the time, the engineering industries accounted for 35% of manufacturing industry, nearly half of the United Kingdom's total exports and was the main supplier of domestic plant and machinery. The Fielden Report (67) argued that the industry was not modernising sufficiently quickly, and that it was particularly lagging in the fastest growing, technically more advanced sectors. Vig has argued that the

Fielden Committee's frank report and DSIR's follow-up campaign received much public attention and contributed to a growing consensus on need for further reform of education, management, and State support programs (68).

By the early 1960s a Lubrication and Wear Group had been formed within the Institution of Mechanical Engineers, and it was within this group that some of the aforementioned problems were highlighted. Moreover it was at this time that science and technology became important issues in British politics (69). Two of the more strategic battle-cries of the successful Labour Party were the welding of science and socialism and the modernisation of Britain's industrial structure. The latter argument was particularly resonant with the state of affairs which mechanical engineers were facing in the fields of friction, lubrication and wear and the development and use of such knowledge in design procedures.

The crucial factor in the emergence of tribology as a distinct field of research was the generous support it received from the government. Mr. Peter Jost, a prominent member within the Lubrication and Wear Group of the Institute of Mechanical Engineers, was acquainted with, or at least 'had the ear of' Lord Bowden who was then Minister of State at the Department of Education and Science. Given the Labour government's
manifesto, Bowden was probably sufficiently swayed by Jost's arguments that a lot of money could be saved in this crucial industrial sector if appropriate steps were taken and that this would, simultaneously, be a concrete realisation of one of the major promises in that manifesto. At any rate, whatever happened in this respect, Bowden did ask Jost to establish a committee of experts to examine the position of British lubrication education and research and to opine on the needs of industry in this field. A working group was established in late 1964 and eventually published the Jost Report (70) in February 1966.

This report justified the importance of its subject area in two ways which were obviously deeply resonant with Labour's electoral pledges:

1. Potential savings were estimated at £515m per annum;

2. Longer term economic, industrial and commercial benefits would accrue if the rate of technological progress was improved by recognition of this important problem. The barriers to this progress could be removed and the reputation of British engineering goods would be enhanced.

To effect these goals, the working group argued that more research and education, and the development of a general awareness of the important potential of the subject throughout industry was required. They also argued that these benefits had not been realised because of the subject's multidisciplinary nature and 'oil-can' associations. In an attempt to remove the latter fetter, the working group thought it necessary to devise a new name. So, following consultations with the editors of the Supplement of the Oxford English Dictionary, 'tribology' – from the Greek 'tribos', meaning 'rubbing' – was decided upon and defined as: 'the science and technology of interacting surfaces in relative motion and of the practices related thereto'.

In February 1966, responsibility for the mechanical engineering industries was assumed by the Ministry of Technology (71). This explains why it was Mr. Wedgwood Benn, the then Minister of Technology, who announced to the House of Commons, on 11 August 1966, the formation of a Committee on Tribology under the chairmanship of Mr. Peter Jost. Essentially, it was set up to advise the Ministry as to how the recommendations of The Jost Report could be most effectively implemented. The major results were the establishment of an Education and Training Committee, three Centres of Tribology research, and a Research and
Liaison Committee which, among other functions, assessed research proposals for the Science Research Council.

Thus by a detailed political process involving engineers, industrialists and civil servants the high level research goal of understanding interacting surfaces in relative motion was established. While the goal of ‘understanding’, it may be argued, is no different from that of science in general, it should be noted that the conditions and justifications for the programme focus the desired understanding within a particular set of constraints which can be best described as goal-oriented. A further point, and this marks a considerable distinction from the model of van den Daele et al. (72), is that the goal is not directed to or emergent from one ‘finalised’ science. Rather is has been adopted by specialists whose interests are or have become directed within the area of tribology from such a wide range of more traditional specialties such as crystallography, metallurgy, fluid mechanics, and various branches of chemistry and physics. Thus, the high-level, ‘metaphysical’ goal was transformed into a more immediate ‘specialty concern’ goal by a process of mediation for each of the relevant specialties – a process we will examine in more detail in the next section. But first, another example of goal establishment.

Environmental Goals (73)

In the early 1960s, the first rumblings of discontent over the despoliation of the environment in the industrialised countries were beginning to make themselves heard. The environment movement originated in the U.S.A., characterised by the appearance of such books as Rachel Carson’s Silent Spring (74) and Barry Commoner's Science and Survival (75). Carson's book, in particular, caught the imagination of the public with an emotive discussion of the damage inflicted upon wildlife by the organochlorine insecticides. Subsequently, the destruction of the environment became an increasingly popular theme for discussion, and in mid-1969 the ‘environmental crisis’ arrived. This arrival was accompanied by a publication explosion and the flood of books and journal and newspaper articles focussed upon the ‘crisis’ has still not completely abated. Similarly, there was a sudden upsurge in the formation of environmental action groups in America and Europe.
A number of key issues dominated the discussions on the environment, particularly the population explosion, the depletion of natural resources (mineral and energy), and the ever-increasing discharges of liquid, solid and gaseous pollutants into the environment. Less tangible worries included the increase in noise, the threat of nuclear war and fears for the general debasement of the quality of life. 'Ecology' quickly became a new watchword, despite that fact that it had originated as a biological concept in the latter half of the nineteenth century; it was seen by many to hold the key to the solution to the environmental crisis. The most important element of ecology lay in its emphasis upon the total interrelatedness and interdependence of all this planet's living matter, including man (76). Man is an integral part of the global ecosystem; his disregard of this fact was the cause of his environmental problems.

The environmental movement was by no means united. A large, predominantly youth-based faction was committed to the environmental cause because of its potential radical implications. This group's enthusiasm was probably responsible for the launching of the entire movement. In the prevalent counter-cultural spirit of the late 1960s, when the opposition to technocratic society was at its zenith, the environmental cause was another direction through which to channel anti-system energies and sentiments; the 'crisis' was seen as a damning indictment of the status quo and technological rationality.

The conservative version of the environmental campaign depicted the problems as technical rather than political. It has been suggested that this conservation ethos, predominantly middle-class, was based chiefly on a consumer's view of nature, which did not demand much reflection further than the recognition that the natural environment was undergoing a process of despoliation. In those days of relative affluence, having achieved the satisfaction of their more material needs, the middle classes had time to turn their attention to less immediate consumptions habits – e.g., the countryside.

The strength and persistence of this public concern necessarily required a response from governments and international bodies concerned to influence them. In 1968, UNESCO convened an international conference upon the use and conservation of the biosphere. It resulted in the drawing up of a four-point plan for a long-term 'Man and the Biosphere' research
programme which can be outlines as follows (77):

(a) Natural environments – the description and classification of the world's ecosystems, and the measures required for their conservation.

(b) Rural environments – the study of 'domesticated' ecosystems, for example associated with agriculture and forestry, to ensure the suitability of techniques.

(c) Urban–industrial environments – the attempt to forecast and avoid harmful ecological and sociological side-effects associated with the use of technology.

(d) Pollution and related phenomena – the study of the effects of the many different sorts of pollution upon man.

In Britain, a Royal Commission on Environmental pollution was set up in 1970 under the chairmanship of Sir Eric Ashby, "to advise on matters, both national and international, concerning the pollution of the environment; on the adequacy of research in the field; and the future possibilities of danger to the environment" (78). In the first report, a general survey was made of the 'state of the natural environment' and it was concluded that although there was no cause for alarm measures it was essential to carry out research into certain areas, such as the pollution of estuaries and coastal waters. Four priorities for government action were recommended: the improvement of public water supply, the control of the disposal of toxic wastes on land, the control of dumping noxious materials at sea and the reduction of noise (79).

Finally, there was the much-publicised United Nations 'Conference on the Human Environment' in Stockholm in 1972. Amongst its lengthy list of proposals were several points which stressed the important role of science and technology in relation to the environment (80). For example:

(Item Number 18): Science and technology, as part of their contribution to economic and social development, must be applied to the identification, avoidance and control of environmental problems for the common good of mankind.

(Item Number 19): Education in environmental matters for the younger generation as well as adults . . . is essential to broaden the basis for enlightened opinion and responsible conduct . . . in protecting and improving the environment.

(Item Number 20): Scientific research and development in the context of environmental problems both national and multinational must be promoted in all countries.
Thus a series of objectives were formulated as part of, and in response to public political pressure and further research was seen as one of the chief agents for achieving them (81). The response to these goals has been the emergence of environmental science, the considerable, if temporary, growth in ecology, and research on environmentalist issues by scientists from almost every conceivable natural and social science discipline, though with a concentration, in Britain at least, in the areas of chemistry, biology and civil engineering.

From these two significantly different cases of goal establishment, it should be apparent that a variety of mechanisms and different patterns of events can lead to the establishment of goals which effectively enter cognitive structures and direct research.

5. Goal Mediation

Transformation of high level goals is necessary before they can become practically useful as guides to scientific work, i.e., before they become instrumentally potent. The resultant 'concrete' goals may have been extensively mediated by scientific and socio-economic considerations. The high level goal may still remain after this process, as a guide to further action, but it will have a changed significance as a result of its practical interpretations.

The first mediating influence will be the perceived state of the relevant science or sciences. Van den Daele et al. in a series of papers (82) have been concerned particularly to demonstrate that 'goal-orientation is subject to the limits set by the internal structure of the sciences'. Through the concepts of 'finalisation' and 'cognitive deficits', they have developed a useful analysis of the way in which the particular stage of development of a science may constrain the kind of goal-direction to which it is amenable.

However such an approach seems excessively deterministic, as successful goal-direction is regarded primarily as a function of the state of development of the 'relevant' knowledge base. The determination, modification and defence of goals is an essentially political process in which the knowledge is used as an ideological weapon, or as 'cultural capital' (83) to enable scientists sharing a particular world view to maintain and extend their explanatory hegemony. Thus the scientific mediation of high-level
goals is anything but a passive process, the outcome determined by the state of relevant knowledge; rather it may well be marked by competition and conflict.

Such competition between scientists of different disciplinary backgrounds in the process of the scientific mediation of the goal of establishing safety levels for environmental lead concentration has been clearly demonstrated by Robbins and Johnston (84). Similar conflict in the legitimation of survey methodology in the social sciences has been described by Bourdieu (85). Weingart has used the term 'relabelling' (86) to describe the response to competition for intellectual authority in which scientists merely 'dress up' their current research activities and interests in order to make them appear relevant to a newly emergent goal. Such a response was prevalent under the ecology label during the environmental movement. A significant proportion of so-called environmental science in Britain can also be described as relabelled (87). The degree of confusion conflict and anomie arising within a formerly coherent group of scientists when faced with the development of a new goal and the requirement for some form of scientific mediation is well demonstrated by Nelkin's (88) account of the impact of the environmental movement on ecologists.

An illustration from a different field of conflict over scientific goal mediation is provided by Hay in arguing for a different approach to the achievement of the solar energy high level goal:

... the solar program, through 1974, appears to have caused greater harm to the early commercialisation of solar energy research than it has been helpful to it. The basic error of federal solar energy research for the heating and cooling of buildings was its initial concept: Failure to begin a state-of-the-art study with a comprehensive analysis of working systems and field data resulted in overemphasis on mechanical (active) systems and disregard of passive and architectural systems. The consultants who were used were best known for many years of engineering research that had minimal acceptance in the market place and in filling national needs. Long-term research proposals, largely restricted to the interests and capabilities of the consultants or advisors were presented as the recommended national policy for solar energy development. Engineering theory and computer analyses were regarded as the high technology assurance of success. Institutions that depend upon endless research by people not noted for practical accomplishments were favoured with billion dollar contracts. Impressive documents and 'sideshows', which in many cases seemed motivating more for political and appropriate support than for practical results, were objectives (89)

As well as mediation in accord with scientific and technical feasibility, high
level goals may be mediated also by socio-economic interests. For example, in the recent evaluation of energy programmes in the U.K. (90) it is apparent and unsurprising, that socio-economic considerations played a major role. Thus the research programmes need to be designed to achieve the goal of supplying energy at an economically competitive cost (translated in specific terms into the generation of power at £x per kilowatt equivalent by a certain date). Other more social constraints require that the energy be produced, stored and transmitted in an 'environmentally acceptable' fashion. Such factors mediate the high-level goals to produce practical goals for research. Clearly the goals of tribology and the other industrial technologies (91) established in the U.K. are strongly determined by economic goals. Indeed one of the specific claims for the establishment of tribology was the saving of £515m per annum. The socio-economic and more specifically political mediation of the goal component of the cognitive structure of the traditionally 'basic' sciences are less evident, but have been demonstrated in a number of cases (92).

The following case of solar energy research offers an excellent illustration of the scientific and socio-economic mediation of high level goals.

Solar Energy

As previously stated, it can be argued that the high level goal of solar energy research is “making the sun work for mankind by exacting large amounts of useful energy from solar radiation” (93). This high level goal has been translated into three general research goals: solar energy conversion, collection and storage, and transmission or transportation. These have been refined by socio-economic interests into three primary areas of concern: thermal energy for buildings, provision of renewable non-polluting fuel sources, and electric power generation. This combination of goals applying to particular concerns has been further mediated by scientific and technological interests to produce a series of specific research goals, including design of water heating and building heating and cooling systems, development of bioconversion and chemical reduction methods to produce fuels, and electricity generation through thermal, photovoltaic, ocean thermal difference, and wind, conversion (94). A wide
range of interests have been involved in the scientific mediation, including the cognitive structures and concerns of scientists from such specialties as photochemistry, photobiology, electrochemistry, heat transfer (a sub-specialty of engineering), materials science, fluid mechanics, building science and architecture.

By this process of mediation, which, it should be noted, is neither static nor 'once and for all', a series of specific goals have emerged which have been integrated to a varying extent into the cognitive structures of the various fields (depending among other things, on 'cognitive deficits' and elite interests) and have provided one source of direction of scientific research in these various fields (95). Of course scientists in different specialties may be addressing quite different specific problems under a common goal. For example, for the electrochemist the storage goal might be resolved into a programme of research on the problems of electric battery research, whereas for the materials scientist the goal might be that of finding a compound with properties appropriate for thermal storage.

A particularly clear illustration of the operation of goal-direction is provided by the development of the sub-specialty, photovoltaic research, over the past twenty years (96). Photovoltaic research is concerned with the direct conversion of light to electricity by a quantum process that effectively avoids the severe limitations that the Second Law of Thermodynamics imposes on thermal systems. The photoelectric effect was discovered by Becquerel in 1839, but only became more than a curiosity in 1954 when three groups of U.S. industrially based scientists independently reported the development of silicon cells capable of conversion efficiencies of 6% (97). From the outset silicon was the favoured material because, though other compounds offered slightly better theoretical characteristics, silicon technology had been thoroughly developed in the electronics industry and was cheap.

The major goals for improvement of these devices were seen as increased efficiency and decreased price (98). The specific goals of the efficiency-oriented research were described as overcoming:

1. radiant energy loss by reflection from the surface of the cell;
2. loss of up to 30% of the hole-electron pairs by recombination;
3. dissipation of electrical energy within the cell as heat (due to the internal resistance of the cell);
4. the presence of a 1.1 micron wavelength energy threshold for photon absorption (99).
These goals directed photovoltaic research after 1954, and the major research was into the mechanism of the photovoltaic effect, the relation between different materials and types and levels of impurities and efficiency, and improved production techniques.

However in about 1960 these goals were almost totally replaced by the new goal, emerging from the U.S. space programme, of developing an autonomous power system suitable for space vehicles. Commitment to this new goal was so complete that little 'terrestrial' photovoltaic research continued. Moreover the new programme was remarkably successful, leading to the lightweight solar cell power systems so vital for the space programme.

In contrast to the terrestrial programme, the specific goals of space-orientated photovoltaic research were the maximisation of power and lifetime and minimisation of area and weight under conditions where cost was not paramount (or even significant). This led to quite different research, focussing on the development and assessment of special materials, the engineering of lightweight arrays and the design of extremely reliable electronic systems. Specific new areas of research included:

(i) Spectral response – because the peak in the number of absorbed photons occurs at lower wavelengths in space, junction design needs to be quite different from that for terrestrial cells, which require a lower resistance and a deeper junction.

(ii) Particle radiation – radiation damage so affected the performance of space cells that this led to the failure of some early space missions. As a consequence, understanding the nature of radiation damage and the design of radiation resistant cells became a priority which generated new theory and completely different cell designs.

(iii) Environmental protection – apart from the very low temperature, the environment of space is relatively benign for electronic devices, at least when compared with the corrosive and abrasive earth atmosphere. As a result extremely precise engineering of devices could be achieved without the need for the protective and robust features required on earth.

The most recent phase of photovoltaic research is associated with the decline of the space programme. For some period there was a failure to re-orient goals to new demands and much of the research after 1970 continued along the lines of the space model. It was only in the wake of
the ‘energy crisis’ of 1974 and a substantial increase in the funding for photovoltaic research as part of solar energy research budgets in most industrialised countries that new goals, and subsequently new lines of research, started to emerge.

6. Goal Evolution

By goal evolution we do not mean the type of radical goal replacement typified in the previous section by the sudden shift to space-oriented goals in photovoltaic research. Nor is the term evolution used with any connotation of positive progress. Rather goal formulation and reformulation is conceived of as occurring in the medium of interpenetrating systems of scientific and social production; such that subsequent statements will also involve the now ‘intermediate’ goal statements and to some extent incorporate them into any new statement, as well as conditioning evolving socio-economic and cognitive perceptions. In other words the interaction of the new knowledge produced under a specific goal with existing knowledge and socio-economic conditions can lead to a redefining of this goal. It evolves in precisely the same way as other elements of the cognitive structure. Thus there is a distinct similarity between this concept of goal evolution and that of ‘goal succession’ developed by Sills (100) in discussing goal changes in organisations, apart from the special cognitive character of scientific goals.

Documentation of goal evolution requires extremely detailed examination of the interaction of goals, cognitive structures, socio-economic constraints and consequent knowledge over a period of time (101). Edge and Mulkay’s excellent study of the emergence of radio astronomy offers indirect evidence of the operation of goal evolution.

In radio astronomy the pursuit of legitimate research goals was followed by the provision of institutional support, rapid growth, the gradual redefinition of research goals, . . . and eventually the extensive alteration of the framework of astronomical thought (102) (our italics).

The development of the field is portrayed in terms of “a dialectic between astrophysical (and cosmological) goals and technical means” (103), with the high level goal indicated by the statement “our ultimate goal is to find
out how the sky works" (104) and specific goals suggested by such as the four aims of the galactic work in the 1951 Jodrell Bank Report (105) and the range of cosmological objectives open once the star survey phase of development was completed (106). They also note the possibility of goal evolution in Mullin's study of the phage group (107):

Thus, although it may be true that the key problem of the phage workers was always that of "how living matter manages to record and perpetuate its experience", it may also be true that this problem was interpreted in very different ways at various points in time, giving rise to new lines of investigation (108).

Other studies which suggest the process of goal evolution include Nelkin's description of developments within ecology during the environmental movement (109) and the emergence of Verfahrenstechnik by Bucholz (110).

7. Conclusion

Ravetz (111) sees the way in which the history of science has been shaped by a faith in science as the ultimate progressive and liberating force on account of its claims to truth and objectivity as a tragedy, because the faith can no longer be justified, whether by epistemological analysis or recent human experience. But if it is tragedy for the historians of science, how much more dangerous is the retention of this nineteenth-century ideology of pure science in an age where the knowledge scientists can produce may be of vital importance to meet pressing new needs and where the competition for resources presents the science administrator with ever more difficult choices of where to concentrate scientific development. It is vital to recognise that the vast majority of science today, whether we like it or not, is 'useful science'.

There has been a considerable growth in the study of science, and undoubtedly many of the models and theories developed in the study of pure science can be adapted to useful science. However, there is a need to progress beyond this 'spin-off' mentality to direct our analysis squarely at the contemporary phenomenon. To this end, we have argued that one of the distinctive features, and a very significant one at that, of modern science, is that it is goal-directed, and only an analysis which incorporates
this can hope to comprehend it. It should be noted that we are not merely claiming that “Disciplines attain phases of development in which their research can be directed to external problems” (112). Rather we are arguing that all modern science is, in principle, goal directed, so that the development of a completely general analysis is possible.

To this end the concepts of goal establishment, goal mediation and goal evolution have been articulated. These concepts, distinct only for analytical purposes, are seen as providing a basis for exploring the interaction between scientific, technical, political, economic and social interests in the shaping of objectives. Goal establishment encompasses the role of the community of elite scientists, as one of many other lobbies, in their struggle to have their interests represented in political programmes, and of the contribution of the level of development of the knowledge-base to what is seen as practicable action. Goal mediation describes the more direct involvement of scientific interests in the mediation of political goals. Cognitive and institutional deficits (113) play an important role in this process, as do quite specific social and economic constraints. Finally, the development of the knowledge-base under goal direction, and also its impact upon social and economic problems can together or separately lead to goal evolution.

The implications of the goal-direction of contemporary science for science policy are considerable. Firstly, a recognition that the production and development of scientific knowledge is determined by the political interaction of socio-economic need with scientific and technical capability, and that goal-direction, occasionally explicitly but more often implicitly, is operating on contemporary science should serve to penetrate and disperse the mystification of the pure science ideology. Secondly, further examination of goal-direction may provide the basis for a more effective linking of knowledge to needs. Of course, the question of ‘whose needs’ remains.

Notes and References

2. ibid., p. 211.
5. In most OECD countries, more than three-quarters and much more in certain cases, of national R & D resources are concentrated in the business and government sectors; see Y. Fabian, A. Young et al., *Patterns of Resources Devoted to Research and Experimental Development in the OECD Area 1963–1971*, Paris: OECD, 1974.
6. Again in most OECD countries, R & D directed towards defence, economic, space and nuclear objectives accounts for approximately 90% of national R & D budgets; see Y. Fabian, A. Young et al., 1974, *op cit.* note 5.
15. The prolonged debate over the Rothschild Report 1971 *op. cit.*, note 9, in the U.K. can be seen as primarily over where this dividing line should be drawn and, once drawn, what form and distance of separation should be established between the entities on either side.
16. The 'science policy' boom of the 1960s, directed as it was in each country by a small group of elite scientists with experience of the science-politics interface could also be interpreted as an attempt to develop a 'scientific' basis for the management of science, and thus to ward off growing political determination of not only the level of funding, but the major directions of growth of research, cf J. Haberer, *Politics and the Community of Science*, New York: Van Nostrand, 1969.
22. For example P. Forman, 'Weimar Culture, Causality and Quantum Theory


25. Case studies include Verfahrenstechnik, biotechnology, cancer research, computer science, educational research, environmental research, heavy ions research and plasma physics.


42. *ibid.*, p. 220.
44. *ibid.*, p. 163.
56. These two examples are drawn from W. van den Daele et al., 1977, *op. cit.*, note 23.
57. The shaping of knowledge by these forces has been clearly demonstrated by P. Forman, 1971, *op. cit.*, note 22 and R. M. Young, 1969 and 1971, *op. cit.*, note 22, respectively.
59. Although high level goals are themselves, hypothetically, the mediated products of other goals, needs and primary socialisation patterns, it is analytically more convenient to take them as points of departure for further mediation.
60. W. van den Daele et al., 1977, op. cit., note 23.
64. Much of this case-study is drawn from an unpublished report, 'A Preliminary Investigation of "Mission Oriented" Specialties with particular reference to Tribology', by B. Gillespie, Department of Liberal Studies in Science, Manchester University, 1975; a paper by C. Knowles, 'New lamps for Old', delivered at a Meeting of the BSA Sociology of Science Study Group, at Manchester in March 1976 also describes the development of tribology.
72. W. van den Daele et al., op. cit., note 23.
76. The ecosystem is the central unit of ecological study which emphasises that no factor operates in complete independence.
79. ibid., p. 46.
81. Thus the Presidential Address at the 135th Annual Meeting of the British Association for the Advancement of Science by Sir Kingsley Dunham concerned the role of science in explicating the environmental threats: 'Prudence demands that no effort be spared to advance those sciences which should be able to show whether the threats are real or imagined, close or distant', British Association for the Advancement of Science, London, August, 1973; A. Mok & A. Westerdip, 'Social Influences on the Choice of Research Topics of Biologists' in R. Whitley (ed.), Social Processes of Scientific Development, London: Routledge and Kegan Paul, 1974, pp. 210–223, chart the influence of the environmental movement on biologists in Netherlands; it should be noted that the relation between the environmental movement and research has been shown to be exceedingly complex, cf. P. Weingart, note 86.
87. Thus, the Environmental Sciences Department at Lancaster University favours planetary geology and radiophysics, while the research at the School of Environmental Sciences at the University of East Anglia is dominated by disciplinary-based geology (Ellis, 1975, op. cit., note 73).
91. The generic title Industrial Technology describes those technologies which, like Tribology, span several disciplines and subjects and which are capable of being applied to a wide range of industries, so as to bring economic benefits on a national scale, viz., terotechnology, corrosion science and materials handling.
92. See note 22.
94. These categories have been drawn from a list of research goals and categories of funding included in NSF/NASA, 'An Assessment of Solar Energy as a National Energy Resource', B-221659, Department of Commerce, Springfield, Va. 1973, and correspond reasonably with those of International Solar Energy Society, Memorandum to the Parliamentary Select Committee on Science and Technology (Energy Resources Sub-Committee), HMSO, London, January 22, 1975, No. 156-i.
95. It should be emphasised that at any time a number of goals, some of which are complementary and some of which are conflict, may apply to a particular research field. The situation in which there is a one-to-one correspondence between goal and specialty may be very unusual.
96. Much of this data is drawn from T. Jagtenberg, 1975, op. cit., note 53.
97. Chaplin, Fuller and Pearson of Bell Telephone Laboratories, Rappaport, Loferski and Lindner of RCA and Reynolds, Leies, Antes and Morainger; efficiencies have since been improved to 11-12%.
98. At 1973 prices, the cost of electricity from silicon cells is about two orders of magnitude above that of the installed cost per kilowatt of a conventional power station.
101. Unfortunately detailed studies of the 'industrial technologies' and solar energy fields has not yet reached a sufficiently advanced stage to allow their inclusion here.
103. ibid., p. 150.
113. *ibid.*