Perspectives on the Emergence of Scientific Disciplines

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Perspectives on the Emergence of Scientific Disciplines

Edited for PAREX by

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Project PAREX (a contraction of Paris-Sussex) was created in 1970 to promote collaboration on an Anglo-French basis between scholars working on different aspects of the social studies of science. Within the last few years, it has become European in scope and broadly interdisciplinary in character. PAREX organises each year one general meeting and several working sessions on particular themes. The secretariat is provided by the Maison des Sciences de l'Homme (54 boulevard Raspail, 75270 Paris Cédex 06).

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Preface

To historians and sociologists concerned with the growth of modern science, the study of disciplines and specialties has been particularly important. The structure and function of disciplines not only reveal essential social characteristics of scientific activity, and the mechanisms of communication, recognition and reward; they also provide access to cognitive features which distinguish one domain from another. In many ways, their study has given impetus to the understanding of scientific development, and to the consideration of social and economic circumstances which may have influenced the rate and direction of that development.

To a large extent, however, this study has proceeded in a fragmentary fashion. Work in the field reveals wide differences in assumptions, methods and explanations, in relation to quite different periods and cultures. Historians have often neglected the importance of analytical categories in describing similarities and differences among disciplines in given historical periods, while sociologists have tended to underestimate the importance of historical context, the vagaries of personal relations, and the pressures on individual scientists as 'actors' in the *arcana theatri* of specialized knowledge. These traditional disciplinary differences have, in practice, been magnified by differences between the scholarly traditions of different countries, which have tended to give different emphases to particular questions and forms of explanation. Perhaps unsurprisingly, generalizations have not been easily forthcoming. Looking to the future, many would agree that it is becoming important to consolidate what we know about the strategies of different disciplines, and the processes by which new ideas and techniques reproduce or alter accepted modes of thought. This task has acquired special urgency in recent years, as the possibility of locating mediations between the 'inner logic' of scientific thought and the external conditions which may advance, retard, or stimulate its application, has become a principal problem not only for scholars but for students of science policy as well.

The possibility that comparative studies, or at least the comparison of results, might lead in the direction of a more systematic approach to the study of disciplines on an interdisciplinary and European basis, prompted PAREX to organize a meeting on the 'Naissance des nouvelles disciplines: conditions cognitives et sociales' in Paris in December 1973. The relative success of this meeting in airing conflicting viewpoints and compelling evidence kindled further interest, and led us to arrange a session on 'Methodology in the Sociology of Science' at York in June 1974. By this time, so much material had been generated along such a vast spectrum of disciplines, that we felt it important to set out the domain as it appeared to us, and to put on record some of our studies, as instalments of 'work in progress'. This book is the result. In an attempt to bring together and clarify some of the important issues involved in the study of scientific disciplines, we have prepared a general editorial introduction. This introduction was drafted by Michael Mulkay, and was then revised in the light of comments from the other three editors.

In presenting this collection of essays, we make no grand promises. The problems involved in agreeing upon common formulations, and comparable categories, are formidable. Nonetheless, we believe our exercise has been constructive and we would like to share the sense of our meetings with others. In the time which has elapsed since these meetings were proposed, four of the papers in this volume have appeared, by agreement, in *Science Studies* (now *Social Studies of Science*) and *Social Science Information*. We are grateful to the editors and publishers for their permission to republish these essays in slightly modified form. Not all the essays presented at our meetings are included in this volume. Those which were not are listed in the PAREX Guide, available from the Maison des Sciences de l'Homme, 54 boulevard Raspail, 75270 Paris Cédex 06.

We are pleased to find that many of the objects which prompted us to meet, have also formed the *terminus a quo* of other groups in Europe. In July 1974, the Institute for Advanced Studies in Vienna sponsored a colloquium which has resulted in a volume entitled *Determinants and Controls of Scientific Disciplines* (Dordrecht: D. Reidel, 1976) edited by K. D. Knorr, H. Strasser and H. G. Zilian. In 1975, a special edition of the *Kölner Zeitschrift für Soziologie und Sozialpsychologie* was devoted to the sociology of science and included much work on the study of new disciplines. This issue is edited by Nico Stehr and is entitled, *Wissenschafts-soziologie – Studien und Materialien* (Opladen: Westdeutscher Verlag). In September 1975, a special meeting on the sociology of science, which included material on new disciplines, was held at York under the joint chairmanship of Nigel Gilbert and Michael Mulkay. A selection of papers from this conference will appear in a special issue of *Social Studies of Science* in August 1976.

The editors would like to thank the Maison des Sciences de l'Homme, the Social Science Research Council and the Universities of Sussex and York for providing us with financial support and secretarial organization for our meetings.

The Editors
January 1976

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INTRODUCTION

Problems in the Emergence of New Disciplines

One of the characteristic features of the modern industrial societies in which we live is their inclusion of a relatively distinct community devoted to the continuous extension of systematic knowledge about the natural world.[1] Particularly since the nineteenth century this scientific research community has come to play a significant part in extending industrial and military technology. It has also come to exert a considerable influence on conceptions of the natural world dominant in the wider society. Moreover, the scientific community has grown even faster than industrial society at large. It has, therefore, taken up an increasing proportion of the resources of industrial societies and has absorbed a growing proportion of their members.[2] Yet despite the evident importance of science in economic, political and intellectual life, our knowledge of the ways in which science develops and of the factors which foster or impede its growth is still fragmentary and highly tentative.

One reason for this is, of course, that scientific development is a highly complex process. Consequently, there has been a tendency for those engaged in its empirical study to select for close attention one strand or a small number of strands from the complicated web of social and intellectual factors at work. Many historians, for example, have dealt primarily with the internal development of scientific knowledge within given fields of inquiry. Sociologists, in contrast, have tended to concentrate on the social processes associated with the activities of scientists; but at the same time they have largely ignored the intellectual content of science. These two broad approaches to the study of scientific development are not necessarily incompatible, even though in the past little attempt has been made to bring them together. It is our hope that these two main perspectives on scientific development, and their several specific variants, can be made to be supplementary and that new opportunities in the social history and the historical sociology of science will more clearly emerge. This book is intended as a move in that direction.

We have collected in this volume a number of recent case studies by historians and sociologists of the development of research fields in the natural sciences. These case studies are mostly concerned with the emergence and growth of particular new fields, although there is one study of the decline of an established area. By choosing studies of this kind we have tried to give the collection a certain coherence. At the same time, however, we have thereby omitted from direct consideration certain kinds of perfectly legitimate approaches to the study of scientific development. We have excluded, for instance, studies of the growth of the scientific community in particular countries and studies of the overall growth of science.[3] This latter type of study has, nevertheless, influenced the way in which we have defined our range of problems. For one of the central conclusions to be derived from an examination of the growth of science in general is that science, as both social and intellectual activity, has evolved by means of a cumulative proliferation of new areas of inquiry, by means of a continual branching out into fields of investigation previously unexplored and often totally unexpected. It is for this reason that we have chosen to concentrate here on the emergence of new research areas. In the rest of this introduction we shall attempt, firstly, to illustrate the full range of questions which can be formulated in relation to this broad problem.[4] We shall then briefly discuss some of the case studies presented in part 1, drawing attention to those questions which were taken as central in particular studies. The basic assumption behind this exercise is that we shall come closer to a systematic and generalised understanding of scientific development only if we have answers to a wide-ranging and comparable set of questions for a considerable variety of scientific fields and for a variety of cultural and national contexts.

In one way or another, all new areas of scientific investigation grow out of prior research or out of the extension of an established body of scientific and/or technical knowledge. Accordingly, it is always possible to trace the intellectual origins of any given field and to show that its emergence at a particular time was at least partly due to previous scientific-cum-technical developments. For example, the emergence of genetics at the turn of the last century can accurately be seen as the end-product of a long line of scientific thought, which can be followed back to the time of Linnaeus and beyond.[5] If we concentrate on this aspect of scientific development, such questions as the following must be asked.

What were the distinctive scientific problems which provided the focus for the new research area? How did these problems come to be formulated? Were they the logical outcome of a major theoretical advance? Or were they the result of attempts to resolve anomalies generated in the course of previous research?[6] Were they unexpectedly derived from the accumulation of empirical data? Or was empirical information sought to solve explicit theoretical issues? Did research techniques play any part in changing the direction of scientific inquiry?

These are all important questions which must be answered if we are to understand why a particular field arose and prospered when it did. In the case of genetics, these questions (or some similar but perhaps more refined set of questions) could be used to provide a framework within which to trace the gradual emergence of the new field throughout the second half of the last century. Thus Darwin's theory of evolution drew particular attention to the nature of the principles of variation of inheritance. This problem eventually became the focus for the new discipline. However, Darwin's work raised more difficulties than solutions in relation to this specific topic. Mendel's laws of inheritance, arising largely out of a long tradition of work into plant hybridization, constituted what later came to be regarded as a major step toward resolving these difficulties; a step which had been foreshadowed in Darwin's own work.[7] But Mendel's research was ignored by a whole generation of scientists largely because, it seems, its central assumptions about particulate inheritance were inconsistent with theoretical conceptions dominant at the time. Leading scientists such as Nägeli were simply unable to perceive the significance of Mendel's results.[8] At the same time, however, research was proceeding on the fertilization process and on the role of the chromosomes, by Hertwig, Strasburger, Weismann and others. This work led to a view of inheritance as arising from the recombination of separate units of hereditary material, that is, as dependent on what are now called 'genes'; and to the rediscovery of Mendel's results by Correns and De Vries. It also led to the widespread use of statistical techniques. From this point on, genetics existed as a distinct area of inquiry in something like its modern form, with a corpus of established knowledge and technique, and with the beginnings of a cumulative research programme deriving from this body of knowledge.[9]

This sketch of the origins of genetics is necessarily brief and superficial. It is intended to do no more than illustrate how we can in principle provide a valuable account of the emergence of a new field by concentrating solely upon a sequence of intellectual developments. But the statements proposed above in relation to genetics can easily lead to quite different kinds of question. At the most general level, we can ask: what were the social processes occurring within the research community which were associated with these scientific developments? More specifically we can raise such issues as: was Mendel's work ignored initially because he failed to communicate with those scientists who would have been more receptive to his work? Did the social organization of the research community affect the dissemination and reception of Mendel's results? What was the intellectual background of those scientists who laid the foundation for modern genetics? What was their position in the research community? Did scientists with a different position and background respond differently to the new scientific developments? These are some of the more obvious questions which come to mind as soon as we begin to regard as problematic the social processes directly associated with specific intellectual advances. We do not intend to try to answer these questions here in detail. Nevertheless, we can illustrate the kinds of answers which might be formulated on the basis of available evidence.

In the first place, we know that Mendel's contact with the wider research community was mediated through the eminent scientist Nägeli.[10] This situation, in which relatively unknown men depend on a particular eminent colleague, is not unusual in science. There is, in fact, considerable evidence to show that in many fields there exists a stratum of leading scientists, each of whom guides the work of a number of less prominent researchers.[11] Thus Mendel's relationship with Nägeli was by no means unique. It was rather a typical product of the social organization of science. Moreover, it had important consequences for the way in which Mendel's work was ıeceived. For it seems likely that the *leaders* in Mendel's field were most committed to the dominant conception of inheritance and, therefore, least receptive to his new ideas.[12] Further support for this view is revealed when we examine the characteristics of those men who eventually succeeded in creating the new field. Firstly, they were rather young. Secondly, either they tended to have come from fields only tangentially related to the study of inheritance or they were recognized as iconoclasts even without their support of Mendelian ideas.[13] In short, these were men who occupied relatively lowly positions within the research community and who were least committed to established notions of inheritance. There is, then, at least a *prima facie* case for arguing that the emergence of genetics as a distinct field of inquiry was dependent on a combination of intellectual and social factors within the scientific community. Mendel's work, and that of his successors, was a response to scientific problems. But the scientific implications of their results were not pursued until there existed a strong group of scientists who, owing to their academic background and their position in the research community, were willing to abandon established conceptions.

There exists now a preliminary body of literature which enables us to view the intellectual development of research areas in science as systematically related to the internal social processes of the research community. In some, and perhaps many, cases the growth of a new area starts with the perception, by scientists already at work in one or more existing areas, of unsolved problems, unexpected observations or unusual technical developments, the pursuit of which lies outside their current field. Thus the exploration of a new area is often set in motion by a process of scientific migration.[14] In the case of genetics, scientists initially came from nine or more different fields.[15] Scientific migration is not a random process, for the scientists moving into a new field tend to come from other areas with specifiable characteristics. In particular, they come from research areas which have experienced a pronounced decline in the significance of current results; from areas where there are few or no avenues of research easily available; from areas whose members have special competence in or knowledge of techniques which appear to have wider application; and from areas which have been disrupted, often by events originating outside the research community, and whose members have consequently no firm commitment to an established field.[16] They tend to move into areas which appear to offer special opportunities for productive research, for the utilization of their particular skills and, consequently, for career advancement.

During the earliest stage of a research area's development, workers at different places take up the same or closely related problems, often unaware of similar work proceeding elsewhere. The lack of communication and the concern with relatively crude exploration of fairly obvious problems leads to multiple discovery, anticipation of results and open competition.[17] An early lead in the competition for results tends to be taken by those with best access to such resources as suitable techniques, graduate students, research funds and publication outlets. It seems likely that a crucial factor in this early phase is sponsorship by scientists of high repute who, by guiding their protégés into new and promising areas, confer legitimacy on the areas of their choice and contribute to the rapid exploration of these areas.[18] The initial results tend to be scattered among various disciplinary journals, general purpose journals and the journals of learned societies.[19] As a result of these first publications, the communication network is extended and strengthened, as some of those previously working independently on similar problems become aware of their common interests and establish informal contact. Where informal communication is not established, growth appears to be seriously impeded.[20]

During the early stages of exploration, research problems tend to be loosely defined and results are often open to widely differing interpretations. This was true of 'genetics' during the 1880s and 1890s. At this stage, in cases where there is a firmly established definition of the field already in existence, any radically new conception is likely to meet with considerable resistance and initially to be strongly supported only by those who are in some way marginal to the area. Gradually, however, as a result of continual debate informally and through the journals, agreement over scientific issues tends to increase. Growing consensus is accompanied by associated changes in intellectual and social processes within the network. For example, publications appear increasingly in more specialized journals. Similarly, the proportion of references to papers by authors not centrally engaged in the field declines markedly.[21] At the same time, a small number of fairly early contributions come to be recognised as paradigmatic and to be cited regularly. As these important contributions become known to workers in other areas and to potential graduate students, the rate of recruitment into what is coming to be regarded as a 'new and interesting field' increases rapidly. As a result, in many cases, the number of researchers active in the area and the amount of published material grows rapidly.

As the network increases in size, research teams and clusters of collaborators form who recruit new entrants to the field and train them from the perspective of the increasingly firm scientific consensus.[22] Both research groups and individual scientists take up specialist lines of inquiry, which are chosen so as to minimise overlap and, consequently, the likelihood of competition.[23] This process ensures that a relatively wide range of issues is explored.[24] Research teams and groupings of collaborators tend to be led by highly productive scientists who exert an important influence on the direction of intellectual development, not only because they are responsible for many of the basic advances, but also because they play a major part in the informal dissemination of information within the network.

Research areas tend to develop in response to major innovations which appear early in the growth sequence, such as that of Mendel in the case of genetics. Subsequent work tends to consist primarily of elaborations upon these central contributions. Consequently, a major proportion of what participants see as innovative work is completed before the field has begun to acquire a significant proportion of its eventual membership.[25] This means that the perceived interest of the field falls sharply after the very earliest period and that, consequently, opportunities decline for making what will be recognised as a notable scientific contribution. As this becomes evident to participants and, more slowly, to potential entrants, the rate of growth decreases.

In some areas, the decline of interesting and/or solveable problems may be followed by a rejection of the existing consensus, and by its replacement with a new and fertile research framework.[26] But this is probably unusual. The central feature of the *typical* sequence seems more likely to be that the pursuit of the problems with which the network was originally concerned either generates a number of new problems and unexpected observations or produces results which are seen to have implications for work in other areas. Thus growth usually turns imperceptibly into decline as recruitment falls away and established members of the network move elsewhere into problem areas in process of formation (see de Certaine's essay in part 1). However, research areas which have become well established take a long time to die out altogether. There is always *some* work that can be done. In many fields, therefore, a few scientists are likely to remain, carrying on the research tradition long after the focus of interest has shifted elsewhere.[27] In some fields, however, although the initial problems are quickly solved, the first period of exploration produces a rapid efflorescence of loosely related avenues of investigation. In such instances the sequence of preliminary exploration, exponential growth and levelling off, can be clearly observed at the level of the specialty or discipline.[28]

This account of the processes of scientific development emphasises the way in which science grows through the branching of new lines of research. It is, therefore, particularly consistent with, and receives support from those quantitative studies in which the cumulative increase in numbers of research papers, separate journals, scientific abstracts, specialist societies, and so on has been described.[29] Indeed the literature summarised above begins to give us an idea of the ways in which social and intellectual processes combine within the scientific community to produce its distinctive pattern of growth and internal differentiation.

Yet this account, focusing exclusively on development inside the research community, is clearly incomplete. For there are several kinds of external influence upon scientific development. It sometimes happens, for instance, that ideas, observations or techniques evolved in the course of practical activities are transmitted to those concerned with the systematic extension of scientific knowledge and that this information changes the direction of their research. As we indicated above, the practical knowledge of plant and animal breeders was increasingly incorporated into the work of biologists, and particularly those concerned with inheritance, throughout the nineteenth century. A similar transmission of technical knowledge, acquired in the course of the development of the steam engine, had a major impact on the scientific study of heat and energy, and on the emergence of the field of thermodynamics.[30] Such 'technical' information can pass into the research community in at least three ways. It can be transmitted by the movement of scientists, technologists or informed laymen from one social context to another. It can also be transmitted through personal contact between scientists and relevant non-scientists. And it can be transmitted by means of formal media of communication, such as professional journals.

The limited evidence available on this issue indicates that the last of these three communication channels is, in general terms, the least important.[31] However, in any specific case, we must be prepared for the possibility that, in one way or another, the direction of scientific advance has been influenced by an input of technical information from outside. We must try, therefore, to answer such questions as: to what extent was scientific development affected by the introduction of technical information generated outside the research community? Who was responsible for the transmission of this information? Did those responsible occupy a special position either in the research community or in the lay community? Were all researchers equally receptive to this information? What social and intellectual factors were associated with a favourable response? Was the transfer or acceptance of information due in any way to a particular set of institutional arrangements? These questions are all fairly obvious, once we have recognised that technical information does flow across the boundary of the research community in both directions. Nevertheless, they are not always posed explicitly in studies of the emergence of new fields and we are sometimes left uncertain whether no technical information from outside was involved or whether the issue was never investigated.

The most interesting of the questions formulated immediately above, for the purpose of our present discussion, is that concerning institutional arrangements. For this question draws attention to another set of external influences upon scientific development, namely the immediate institutional contexts in which scientific research is undertaken. There are a number of studies which show that the institutional context of research can affect both the rate of scientific growth and also its direction.[32] It seems likely that genetics, for example, was able to develop particularly quickly in the US during the first decade of this century, at least partly because the American university system was expanding at that time and also because American agricultural colleges and experimental stations provided a reasonably receptive environment for the new genetics and, in some cases at least, a context in which research could be undertaken.[33] A somewhat different example of how changes in a national academic system can affect the emergence and growth of new areas can be found in the case of the medical sciences in Germany during the second half of the last century.[34] Between 1850 and 1870 physiology emerged there as a distinct discipline. The number of university chairs expanded quickly in this field and the number of discoveries increased dramatically. But the German university system itself did not expand. Consequently, by the 1870s all the possible chairs in physiology had been established and occupied by relatively young men. From this date, therefore, the attractiveness of a career in physiology declined markedly and there was an immediate shift of interest within the medical sciences away from physiology toward such fields as pathology, pharmacology and experimental psychology, where opportunities for professional advancement were less restricted.[35] As a result of these processes, the rate of innovation in German physiology fell sharply and remained low for a generation; whereas in the other medical sciences new departures were set in motion.

In the light of these examples, it seems necessary in any comprehensive account of the emergence and/or growth of new scientific fields to consider the part played by the academic context and by associated institutions. Accordingly, questions such as the following should be raised. Did research into the new area originate and spread within the university system or within some other social context? Were any changes occurring in this social context which were especially favourable or unfavourable to the exploration of the new field? Did entry into the new field confer any special social or economic advantages? Clearly, answers to questions of this kind will in some cases contribute to our understanding of the emergence of new fields. But, once again, the answers that we are likely to get will lead us toward a new set of questions. They will lead us, in particular, to consider the economic and political processes at work in the wider society.

We suggested above, with special reference to genetics, that a new academic area would become more easily established if its inception coincided with the expansion of the university system. But systems of higher education do not expand in a social vacuum. Rather they tend to respond to changes in the national economic situation and to changes in political policy and political context. The ways in which the economy and the political process impinge on scientific development are varied, often highly complex, and in general not well understood. We shall offer just a few illustrative examples. In the case of genetics, the availability of agricultural colleges and experimental stations interested in research on inheritance was merely one by-product of a broad Federal government policy designed to help American agriculture.[36] Situations like this, in which government support for an area of public interest fosters the growth of a clearly relevant scientific field, are probably fairly common.[37] In contrast, the expansion of the German university system during the last century, and the accompanying emergence of many new fields of inquiry, appears to have been an indirect consequence of the dynamics of the German political structure. Because the German cultural area exceeded the limits of any single German state, no central national university existed. Instead there was a large number of separate universities, all of which were in competition for academic reputation. Thus, it has been argued, the university system was decentralized and competitive because the political system was decentralized and competitive. Accordingly, as the German universities sought to outdo each other, they became more receptive to supporting new areas, in which none of their competitors could have established a commanding lead.[38]

These are examples of historical connections between political structure and policy, on the one hand, and scientific development, on the other hand. There are, in addition, instances where economic factors have been particularly important. The expansion and reform of science education in Britain during the later part of the last century is a good illustration of how changes in the economy can influence the institutional context in which science evolves. For the reorganization of British science teaching at this time, which brought with it a radical alteration in the nature of scientific research and recruitment of scientific personnel, was a direct response to the apparent economic decline of the United Kingdom in comparison with scientifically more advanced societies, and in particular, in comparison with Germany.[39]

The impact of economic factors on the development of scientific disciplines has not always been mediated through changes in the institutional context of research. The work of Pasteur, for example, on the fermentation of beer and on silkworms, in the course of which he began to develop his germ theory of disease and to lay the foundation for the discipline of bacteriology, was a direct response to the 'needs' of French industry.[40] But Pasteur's scientific ideas were by no means produced solely by his study of the technical problems facing the manufacturers of French beer and silk. Rather Pasteur's analysis of these practical problems was guided by conceptions he had already begun to develop in the course of prior, and more exclusively scientific, researches.[41] If this example is at all typical, it seems likely that the direct connections between the economy and scientific development will involve a two-way process and will depend greatly on the flow of technical information.

The connections between scientific development and economic and other practical problems are perhaps most obvious in the biological and medical sciences. Thus many of the discoveries and, even more, the changes of outlook that have transformed biology during this century have been associated with attempts to satisfy the needs of practice; for example, in fields such as entomology, ecology, immunology, and so on.[42] But links of this kind between broad social developments and the evolution of scientific knowledge are not necessarily confined either to the biological sphere or to the twentieth century. It has been argued, for instance, that the emergence of modern physics in the seventeenth century was not unrelated to the rise of the bourgeois class and military and economic demands; and that the focal scientific problems of classical physics, such as problems of floating bodies and projection of bodies through resistant media, were direct responses to technical issues which had become important as a result of broad socio-economic changes.[43]

In the light of the earlier discussion, it seems to us unsatisfactory to claim that broad changes in the structure of society have determined the course of scientific development in any simple, direct or uniform fashion. It appears necessary, nevertheless, to formulate a series of questions relating to the influence upon science of economic and political factors. For example: did scientists respond directly to specific technical problems in the economic sphere? Were there changes in the economy which affected governmental or industrial support for particular types of scientific research? Was the inception or the growth of the field influenced in any direct or indirect way by special features of the political context? These general questions must, of course, be made much more specific in the study of particular fields. The value of such general formulations is that they help us to ensure that we do not ignore factors which may be of crucial importance in specific cases.

In various ways, then, the internal development of scientific research has been influenced by the wider political and economic context.[44] In many cases this influence has been relatively indirect, largely because those responsible for economic and political policy have in the past tended to assume that direct intervention by laymen would only disrupt pure research and that an autonomous scientific community would not fail to set in motion a more or less continuous supply of practically useful and beneficial knowledge. Consequently, although the support given to research by both government and industry has been on a selective basis, academic scientists have been left relatively free in Western countries to determine the detailed distribution of funds in accordance with scientific criteria. In recent decades, however, the cost of much scientific research has increased dramatically. As a result, governments, which provide most of the funds for pure research, have come to require a more tangible return for their support. Increasingly, therefore, attempts have been made to assess the benefits of research in relation to economic growth, welfare, armaments and national prestige.[45] Furthermore, governments have become increasingly committed to a 'policy for science' which reflects social, economic and political, as well as scientific, priorities.[46] Thus, science has come to be seen as competing with other areas of governmental policy for scarce resources. Accordingly the view has formed that, despite the internal logic of scientific development and the undeniable element of unpredictability in scientific advance, an explicit policy must be formulated to control the direction in which science evolves in such a way that 'the maximum social benefit' is extracted from scientific knowledge.[47]

In addition to this change of view in official circles, there has been an evident decline of general support for science. One sign of this is the recent fall in recruitment into science, which has been noted in Western Europe, Britain and the USA.[48] Another sign is the growing momentum of an increasingly critical perspective on science. From this new perspective, science comes to be seen as inseparable from such unwelcome developments as pollution and the hydrogen bomb; and the activity, even of the academic research scientist, is more and more regarded, not as a morally neutral search for truth, but as embodying a narrow, and in some respects equivocal, moral position. These views are by no means confined to laymen. Many of the leaders of the scientific community appear to have become aware of the difficulty of the moral problems facing them. In addition, there are signs of more widely based movements of opinion within the scientific community. For instance, certain national societies for social responsibility in science have considered requiring their members to make an ethical statement of principle concerning their intentions in research. Similarly, a number of schools of 'critical science' have developed recently whose aims – to investigate and understand the consequences of modern science and technology and to ensure that any abuses are abolished or controlled – are both political and scientific.[49]

We do not know at present whether this climate of opinion with respect to science will be lasting; nor do we understand in detail how it is likely to influence intellectual advance in science. If it does last, if critical debate about the place of science in modern society continues and if explicit policies embodying attempts at rational control of science become permanent features of modern government, it seems likely that non-scientific considerations will come to play an increasingly important part in determining the direction of scientific development and that academic scientists will have to become significantly more receptive than in the past to the requirements of lay audiences. Those engaged in the study of science must, therefore, be ready to investigate the nature of the possible links between scientific development and views of science current in various sectors of society at large.[50] In the case of many past developments, the availability of research personnel and the existence of a general support for science were not problematic. In the future, however, this is unlikely to be so. There is every indication that the supply of new researchers will continue to diminish and that there will be an increasing concern among laymen, politicians and scientists to regulate scientific development in accordance with social and moral standards as well as purely scientific criteria.[51] As a result, especially in the case of scientific fields which have emerged in the last decade or so, we must be ready to pose such questions as: was this field particularly attractive to new entrants to science and, if so, why? Was it seen as being especially significant in relation to specific social values? Was there any negotiation involved between scientific leaders and those able to provide funds and facilities? Was there any organised or diffuse movement among scientists (or among laymen) in its favour?

So far in this introduction we have drawn attention to a series of what can be called, for the sake of convenience, 'problematic spheres' in relation to the emergence of new areas in science. These may be summarized as follows:

— internal intellectual processes
— internal social processes
— external intellectual factors

— immediate institutional context
— specific economic and political factors
— diffuse social influences.

The order in which these items are listed does not represent their degree of significance. How these factors interact in particular cases remains empirically open. What we have tried to show above is simply that every sphere can, at least in some instances, influence appreciably the course of scientific development. More specifically, we have illustrated how these spheres may be seen as bearing on the *rate* of scientific development, on the *direction* of scientific development, and on the intellectual *content* of scientific development.

These important notions of rate, direction and content, which have been implicit in the preceding discussion, need a little clarification at this juncture. By 'rate of scientific development' we are referring to the speed with which scientific information accrues within a particular field or within a number of related fields. It can be measured, in a manner which is crude but adequate for many purposes, by counting the number of researchers active in the area or the number of research reports published in the area over a period of time.[52]

Although rate of development is, in most cases, closely linked to direction of development, the two notions must be kept analytically distinct. 'Direction of scientific development' refers to the exploration of one area of intellectual endeavour rather than other areas. To use an example given above, certain facets of the German political and educational systems appear to have influenced the direction of scientific development during the last century by encouraging scientists to search for and to open up new fields of medical research. Of course, these changes in direction entailed changes in the rate of development of the various medical sciences involved, with older fields slowing down as the new fields began to grow. However, changes in the rate of growth need not always involve alterations in direction. For example, new government policies may make available more funds and more research personnel for a relatively mature field of inquiry which is seen as having important practical implications. In such a situation, the rate of development may accelerate within this field without there being either a change in the direction taken by scientific research or even a fall in the rate of development of other areas.

There can be no doubt that both the rate and the direction of scientific development are influenced by social as well as by intellectual factors. It is by no means so clear that the content of science – and by this we mean scientific principles, explanatory propositions, and empirical findings –

has been or can be *directly* influenced by social factors. Certainly it has been argued, by both philosophers and sociologists of science, that although the speed of scientific advance and the direction it has taken may be affected by social processes, the actual content of scientific thought is an outcome solely of the internal logic of scientific ideas and scientific research methods.[53]

It is clearly important to bring to bear on this point the empirical findings provided by case studies. In our view, none of those contained either in this volume or elsewhere, demonstrate unequivocally the effect of social influences on the content of scientific thought. In the case of radio astronomy and in that of radar meteor astronomy (see the essays by Mulkay and Edge, and by Gilbert), for example, it is certain that the technical advances made in the course of war-time research on radar, as well as the social groupings then formed, were crucially important in setting in motion the growth of these new research areas immediately after the Second World War. However, there is no way in which we can discover from the evidence at present available whether the propositions in relation to meteors or radio emission from celestial phenomena which are now generally agreed, would have been any different if their origins had been totally independent of external influences. Similarly, in the case of tropical medicine (see Michael Worboys' essay), it can reasonably be argued that political factors merely hastened the application of biomedical perspectives to diseases such as elephantiasis, leprosy and malaria; and that the way in which these diseases were interpreted by the practitioners of tropical medicine was determined entirely by 'scientific' considerations.

The case of agricultural chemistry (see the first essay in this volume) comes close to demonstrating the impact of external economic and demographic factors on scientific content. In this case it is argued that, due to the pressing need to increase agricultural yields and within the context of developments in chemistry, practical goals were translated into a specific scientific development, namely Liebig's theory of the cycle of plant growth, which allowed the production of artificial manure. But the influence of these external factors on the content of a particular scientific development must not be mistaken to refer to a simple uni-directional and *direct* process. Rather, the case of agricultural chemistry demonstrates the extremely complex nature of this process, in which previous scientific knowledge, economic problems, and political and institutional factors may all interact. We only know for certain that by this process external influences are 'translated' into scientific knowledge which remains subject to the internal logic of science.

The last essay in this volume, on the 'Resistance and Receptivity of Science to External Direction', deals with one attempt to conceptualize this process. Perhaps the only situation in which a conclusive inference could be made in relation to this issue would be one in which there were two available scientific perspectives which dealt with the same range of phenomena and which were judged by participants to be of equal scientific merit. In such circumstances, it might be possible to show that support for one perspective rather than another was a consequence of religious, political, economic, or other social influences, and not solely a consequence of scientific judgments. It is, however, unlikely that such a clear-cut situation could ever be observed. For example, even if scientists' adoption of one perspective rather than another was 'really' due to political factors, those involved would probably tend to justify their choice on scientific grounds, thereby making it difficult, if not impossible, for the investigator to show that the political sphere exerted a determining influence on the content of scientific ideas.

There is, then, considerable difficulty in showing that social factors, whether internal or external, actually mould the *content* of scientific ideas.[54] It is not surprising, therefore, that in the studies below little attempt is made to establish such a strong relationship. Rather the main concern is to describe how social factors have influenced the incidence, dissemination and acceptance of new scientific ideas and, thereby, the rate and direction of scientific development. These studies also try to show how scientific innovations have exerted a reciprocal influence on accompanying social developments. These reciprocal relationships can be clearly seen in the case of radio astronomy. This specialty would not have emerged when it did, nor would it have grown up so quickly, if radar techniques developed during the war had not been available or if university research groups had not been formed by scientists who had been employed in war-time radar research establishments. At the same time, however, research into radio emission from celestial objects would not have been pursued with such energy if the scientific results had not appeared significant in the light of current conceptions. The appearance and rapid development of radio astronomy in Britain and Australia immediately following the Second World War was clearly due to a conjunction of social, scientific and technical factors. That all these factors were involved in the emergence of the new specialty can be seen from the fact that, where this conjunc]ion did not occur, the growth of radio astronomy was much more hesitant and largely dependent upon prior scientific and social developments in these two countries.

A dynamic relationship between intellectual and social processes can also be observed in the case of physical chemistry (see the essay by R. G. A. Dolby). In this instance, the growth of the area was facilitated by the existence of peripheral regions in the scientific community within which the new perspective could emerge and prosper; and by the formation of a 'school' around the figure of Ostwald, which played an important part in sponsoring the new ideas of physical chemistry and in attracting and training new recruits. Once again, however, these social factors combined with intellectual developments. Ostwald and his school were able to make such a major intellectual impact at least partly because they were able to systematise a considerable body of previously scattered scientific work, and also because they based their claim for scientific legitimacy on powerful new theories which in due course proved to be fruitful in various areas of chemical inquiry.

As we have already noted, the relationship between intellectual and social processes is further illuminated if we look at the role of the institutional setting of science. Institutions are social processes which have achieved a considerable degree of permanence and perceived legitimacy. Science is institutionalized in universities in the form of teaching and research activities. The organizational structure of the university system acquires its own weight and dynamics, for instance, by social separation between disciplines on intellectual grounds, by the formalization of recruitment and resource allocation procedures, by its dependence on state authorities or private boards, and so on. As a result, although the structure of the academic world can become a barrier to scientific innovation, it is sometimes possible for scientists to use the social dynamics of the university system to gain support and acceptance for new intellectual departures. Thus the proponents of physical chemistry were able to take advantage of the diversity of the German university system to obtain a secure base and to set in motion the cumulative growth of their field, despite the intellectually and institutionally dominant position at that time of organic chemistry. In some instances, the impact of the immediate institutional context may be selective, favouring one specialty or discipline rather than another. To show this clearly, however, we need to demonstrate that the institutional context operates differentially upon scientifically equivalent fields. At other times, it seems that changes in the institutional context affect a wide range of areas in a more or less uniform fashion. Thus the expansion of the American university system at the turn of the century helps to explain the rapid establishment in that country not only of physical chemistry, but also of many other fields.

In the case of agricultural chemistry we have an instance where scientists deliberately used institutional mechanisms in order to overcome opposition from established disciplines and to facilitate the diffusion of their own scientific convictions. Agricultural chemistry was a discipline whose development was strategically planned in response to requests from outside the scientific community for a chemical science which would bring about a definite improvement in agricultural productivity. Liebig, the major figure involved, was convinced that when a new theory replaced an old one it tended to stand in direct opposition to it. Consequently, he believed that it was important to promote the growth of the new perspective through the training of students. Within his own laboratory he adopted an explicit policy of directing students into research in agricultural chemistry. This alone could not have been successful, however, if Liebig had not also taken steps to ensure that career opportunities were available for his students.[55] In reports on the situation of chemistry in Prussia and Austria he attacked the incompetence of existing teachers in order to gain influence over future appointments in the interests of his own students. In addition, he was in command of the leading international journal for organic chemistry, in which he gave his field and his students a prominent place. Finally, Liebig was not only influential in establishing professorial chairs for agricultural chemistry in several universities, but he was also able to restrict the development of the agricultural academies, whose members tended to oppose his views.

Although in the case of agricultural chemistry the strategic use of institutional mechanisms was particularly pronounced, the development of many scientific specialties shows a similar pattern.[56] The nature of the institutional context and the use of that context made by innovators are often crucial factors in the establishment and diffusion of novel ideas in science. However, the operation of institutional mechanisms alone can explain in full neither the success of innovations nor the removal of resistance to these ideas. Liebig, for example, was not recognised as successful until he had demonstrated the agricultural superiority of his artificial manure and, by implication, the validity of his theory.

In the chapters which follow, the emphasis placed upon intellectual, institutional and other factors unavoidably varies, according to the nature of the case under study and the perspectives of particular authors. Consequently, although the connections between the development of scientific knowledge and various problematic spheres are examined in part 1, no