Texto nº 2

The new production of knowledge

The dynamics of science and research in contemporary societies

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perceived as typical of business firms and also of military establishments. Tacit knowledge is not exclusive to business firms since it is present in the research practices of any scientific and technological community. Contrary to what may appear to be the case, the competitive advantage of a firm lies less in its pool of proprietary knowledge than on its base of tacit competence. As proprietary knowledge is utilised it is subject to imitation, adaptation and replacement and gradually loses its market value. Tacit knowledge can only be acquired by hiring the people who possess it and it is the principal way a firm may replenish its basket of unique technologies.

The prevalence of tacit over proprietary knowledge brings the culture of technologically advanced firms much closer to academic cultures than is usually assumed. The isomorphism between these structures allows frequent interactions which lie at the root of the perception that science, technology and industry are moving closer together, and support our contention that interactions are increasingly taking place in the context of application. They share, in addition, a common behavioural pattern. Each is driven in part by a process of competition and in part by the need to collaborate. In science, competition is for academic recognition while in the technology system it is for technical efficiency, and in industry for that particular type of efficiency that generates a financial return. In each regime, individuals and teams try to establish as dominant their particular ways of doing things, their respective paradigms. Dominance depends on creativity which is a matter of skills, resources and organisation. Each operates in a regime where resources are limited and while success may relax this constraint, it will never entirely remove it. To some extent, this limitation can be met by collaboration. But more is involved in collaboration than the sharing of resources. As we shall see, the context of use is increasingly one where the best scientists and technologists meet and where they develop novel theoretical ideas and practical procedures.

The general significance of the shift from Mode 1 to Mode 2 for science and technology being so posited, we will outline in the remainder of this chapter two different sets of questions. First, we will address some of the major phenomenological aspects of Mode 2: its manner of producing knowledge in a transdisciplinary way, and the way quality control is exercised over the results of that production. Second, we will start to explore the dynamics of Mode 2 in terms of an increase in the heterogeneity of its constituents and of an increase in the density of the constitutive communication processes it exhibits with society, between scientific practitioners, and with the physical and social worlds. This increasing heterogeneity of constituents and of constitutive communications make explicit how socially distributed knowledge is at the core of Mode 2.

On the Phenomenology of the New Mode of Knowledge Production

Transdisciplinarity

Transdisciplinarity is the privileged form of knowledge production in Mode 2. It corresponds to a movement beyond disciplinary structures in the constitution of the intellectual agenda, in the manner in which resources are deployed, and in the ways in which research is organised, results communicated and the outcome evaluated. In that regard Mode 2 derives its impetus from a context which is totally different from the one which prevailed before the rise of specialised, disciplinary science in the nineteenth century when the scene might have been described as non-disciplinary. Mode 2 is evolving from a strongly disciplinarised context and as we have already stressed, knowledge produced under these conditions is characterised by aiming a use or action, that is towards 'application' in its broader sense.

In the production of transdisciplinary knowledge, the intellectual agenda is not set within a particular discipline, nor is it fixed by merely juxtaposing professional interests of particular specialists in some loose fashion leaving to others the task of integration at a later stage. Integration is not provided by disciplinary structures – in that regard the knowledge process is not interdisciplinary, it cuts across disciplines – but is envisaged and provided from the outset in the context of usage, or application in the broad sense specified earlier. Working in an application context creates pressures to draw upon a diverse array of knowledge resources and to configure them according to the problem in hand. The context of application is already intellectually structured, even if only in very general terms and provides heuristic guidelines. The search for a fundamental computer architecture is already a search for an architecture and not something else. Some participants may have a general idea of how the search should proceed and what knowledge and skills are required. There can, of course, be more than one view as to the best way to proceed and such divergences may fuel a process of competition. A brief description of the value of transdisciplinarity, and why it so often fails is given in Box 1.2.

Box 1.2
On transdisciplinarity

Why is transdisciplinarity valued so highly and why do so many efforts which are undertaken to establish it fail?

The problem with transdisciplinarity is the following: precisely because it so universally acclaimed as something positive, everyone believes it can be brought about just by aspiring to it. A closer look, however, reveals that much which is thought to be inter- or transdisciplinary in reality amounts to a mere accumulation of knowledge supplied from more than one discipline.

The yearning for inter- or transdisciplinarity and much of he rhetoric to which it is embedded is rooted in the nostalgia for an epoch when the 'unification of science' still appeared to be possible. In some fields, like physics, the 'dream of a final theory' is still very much alive (Weinberg, 1993). Such dreams reveal an understandable nostalgia for a pattern of knowledge production which is the exact opposite of what seemingly prevails today; the relentless increase in further specialisation of scientific knowledge and its diversification into ever more narrow areas. These processes and the speed with which they take place signal the breakdown of a common understanding across scientific disciplines, the loss of an intellectual common grasp for their development and the impossibility of communication across specialisms. Even among neighbouring specialities and among subfields within one discipline increasing difficulties are experienced in maintaining standards of expert scientific literacy. These tendencies are underlined by the proliferation of ever new scientific journals which explore more and more specialised intellectual market niches, increasing complicity in the classification systems of knowledge, a plethora of conferences, meetings and other signs which are the outward manifestation of the growth of the scientific technological labour force and its further specialisation and diversification.

The positive esteem accorded to inter- or transdisciplinarity is the expression of the wish to reinstate communality.

Since transdisciplinarity has become a value in its own right, it is often naively believed that striving for it is insufficient ground for achieving it. Experience, however, shows that numerous deliberate attempts to set it up, often with the best of intentions, were doomed to failure, unsuccessful projects are especially high when centred around university teaching.

There have been many attempts to discern pluri from inter- and transdisciplinarity. Following the definition given by Erich Jantsch (1972), pluri-/multidisciplinarity is characterised by the autonomy of the various disciplines and does not lead to changes in the existing disciplinary and theoretical structures. Cooperation consists in working on the common theme but under different disciplinary perspectives.

Interdisciplinarity is characterised by the explicit formulation of a uniform, discipline-transcending terminology or a common methodology. The form scientific cooperation takes consists in working on different themes, but within a common framework that is shared by the disciplines involved. Transdisciplinarity arises only if research is based upon a common theoretical understanding and must be accompanied by a mutual interpenetration of disciplinary epistemologies. Co-operation in this case leads to a clustering of disciplinary rooted problem-solving and creates a transdisciplinary homogenised theory or model pool.

In contrast to the widely held views and attempts that have been undertaken to set up transdisciplinarity by fist only, we do not argue for transdisciplinarity as a positive value per se. We see the emergence of a new mode of knowledge production as resulting from wider societal and cognitive pressures. It arises out of the existing dysfunctionalities and breakdowns of disciplinary modes of problem-solving. In the language of self-organisation, it emerges only once sufficient disturbances shake up the system of knowledge production. While it can be argued that the successful establishment of a particular field as transdisciplinary or, in the terminology of Erich Jantsch, as a clustering of disciplinary rooted problem-solving methods, is likely to mimic in the longer run the successful institutionalisation of a discipline, and hence becomes a discipline itself, our interest is in knowledge production as an ongoing process and the changes that occur in the ways how it is produced. A transdisciplinary mode consists in a continuous linking and relinking, in specific clusterings and configurations of knowledge which is brought together on a temporary basis in specific contexts of application. Thus, it is strongly oriented towards and driven by problem-solving. Its theoretical-methodological core, while cross-cutting through well-established disciplinary cores, is often locally driven and locally constituted, thus, any such core is highly sensitive to further local mutations depending on the context of application. The transdisciplinary mode of knowledge production described by us does not necessarily aim to establish itself as a new, transdisciplinary discipline, nor is it inspired by restoring cognitive unity. To the contrary, it is essentially a temporary configuration and thus highly mutable. It takes its particular shape and generates the content of its theoretical and methodological core in response to problem-formulations that occur in highly specific and local contexts of application. Just as the debate about nature and nurture and about the adaptability of human culture to biological universals has moved beyond an 'either/or' answer and focuses instead on specific modes of learning and cultural responses, so it is with scientific and technological knowledge production: it is the specific mode that shapes the outcome.

Still, the search within a context of application is not a haphazard affair. Knowledge production will be guided by theoretical considerations as well as by the limitation of experimental methods. And though it takes its starting point from the intellectual frameworks of all those who participate in the search, it soon leaves them behind to follow new paths. Over time a new framework, a Mode 2 framework, will evolve – for example, the basic architecture will be hit upon. It will be different from any of the constituent frameworks, yet could not have been developed without them. The chosen Mode 2 framework will usually guide a great deal of further work, but it might happen that all those involved will return to their original discipline while others will be recruited to take the process further. The new Mode 2 framework constitutes a new point of departure from which further problems will arise and if they are demanding enough, the same or different individuals will be drawn to work on them. Disciplines are no longer the only locus of the most interesting problems, nor are they the homes to which scientists must return for recognition or rewards. Over a lifetime these 'experts' may well stray a long way from their original disciplines, having worked in their careers on a wide array of stimulating problems.

In transdisciplinary contexts, disciplinary boundaries, distinctions between pure and applied research, and institutional differences between, say, universities and industry, seem to be less and less relevant. Instead, attention is focused primarily on the problem area, or the hot topic, preference given to collaborative rather than individual performance and excellence judged by the ability of individuals to make a sustained contribution in open, flexible types of organisation in which they may only work temporarily. None the less, a new mode of knowledge production cannot simply force its way onto the institutional stage. A certain number of basic conditions must be fulfilled if it is to become institutionalised. The search for understanding must be guided by agreed models and sets of experimental techniques, its articulation must follow the canons of empirical method, its conclusions must be communicable to a wider community and be repeatable by others. To qualify as such, knowledge

must form an organised stock and its methods of working must be transparent.

Scientific results are not generated in a vacuum. Social processes operate throughout, though they are perhaps more evident at the beginning and at the end: that is when the agenda is decided and the results evaluated. It is here in legitimating its activities vis-à-vis Mode 1 knowledge production that the novelty of transdisciplinary activity is most evident and where tensions arise. For example, while it is true that transdisciplinary research is, in its mode of organisation, more fluid and flexible, it also seems to be more transient. It is perhaps for this reason that in large projects, such as the mapping of the human genome, the constituent expertise remains distributed throughout. There seems little pressure to centralise such large projects on a permanent basis and continuous training of young researchers, technicians and postdoctoral fellows takes place through mobility in existing networks. This mode of training stands in sharp contrast with the monopoly held by the university departments which award the PhD as a prerequisite for entry into Mode 2 work settings.

While knowledge production within traditional disciplinary structures remains valid, interesting and important, Mode 2 is growing out of these structures and now exists alongside them. Although they are at an early stage of development, some of the practices associated with the new mode are already creating pressures for radical change in the traditional institutions of science, particularly the universities and national research councils. Not surprisingly, some of these institutions are resistant particularly to those changes which seem to be threatening the very structures and processes which have been created to protect the integrity of the scientific enterprise.

Quality Control

To some extent, the identification of this change hinges on what is meant by science and technology. What counts as knowledge is, in both cases, to a large extent determined by what scientists and technologists say shall count, and this involves, implicitly if not explicitly the norms governing the ways they produce knowledge. Not only do those claiming to produce scientific knowledge have to follow certain general methods, but they also must be trained in the appropriate procedures and techniques. To be funded, researchers must formulate the problems on which they want to work in specific ways recognisable to their colleagues, and they must be scrupulous in reporting their results to a community of their peers using prescribed modes of communication. Science is a highly structured set of activities involving a close interaction between technical and social norms. Of course, not all science is produced in exactly the same way, but technical and social norms are accommodated differently in each specialism which in turn, becomes absorbed into the larger community by a process of professionalisation and institutionalisation. Technology is a similar form of knowledge governed intellectually by structures which guide research and suggest likely solutions, and socially by groups of peers who evaluate solutions and develop codes of best practice.

By contrast, what is produced outside of these structures can be problematical. Many argue that knowledge cannot qualify as scientific if it is produced outside its legitimating structures. A tension with established structures will arise when any scientist acts in a manner different from that prescribed by their specific set of technical and social norms. But as long as the numbers of such deviants are not significant, no threat is presented to the social control of knowledge production. However, when significant numbers of scientists choose to work on problems that lie outside their specialisms, when they form teams with other specialists to work on complex projects, when in doing so they enter into arrangements with other social institutions which broaden the constituency of interests involved in setting agendas and priorities, and when performance is evaluated by an expanded peer group, then the legitimacy of outputs may be called into question. In most industrialised societies, the higher education system has seen to it that sound research procedures have been diffused and the number of opportunities to use science has been expanded. The norms that have governed the production of scientific knowledge need to be adapted because the current ones are no longer perceived to be adequate for the continuing development of science itself.

In discussing knowledge production in terms of the emergence of Mode 1 alongside Mode 2, we have to clarify where the differences lie. Of these, an essential one concerns changes in the mechanisms which assess the quality of knowledge produced. In Mode 1 for both scientific and technological knowledge this is a matter of establishing a provisional consensus among a community of practitioners. The judgements of this community form a powerful selection mechanism of problems, methods, people and results. It is a crucial social process to maintain standards and its prerogatives are protected because rigorous control of quality is seen to be the principal way to maintain autonomy over the internal affairs of the community. Quality control has two main components: one is institutional and concerns the spatial position of a particular research activity in the cognitive landscape; the other is cognitive and pertains to the social organisation in which such research is performed.

The dependence of quality control on institutional space In Mode 1, control is exercised by different types of knowledge producing institutions each of which has its own boundaries, structures of apprenticeship and rules of behaviour. Such institutions include, for example, universities, national academies and the professional societies. Each has different ways of controlling membership, some provide training, establishing procedures whereby knowledge is produced and validated. Because knowledge production in Mode 2 occurs within transient contexts of application it is unlikely that the communities of practitioners who exercise quality control will be backed up by relatively stable institutions such as one finds in Mode 1. Looked at from the point of view of Mode 1 such a process of quality control necessarily appears as dislocated. It takes on transient and temporary forms, exhibits fluid contours and provisional norms, and occupies temporary institutional spaces which can accommodate knowledge producers with many different institutional affiliations, either simultaneously or sequentially.

The dependence of quality control on the social organisation of research The second component of quality control relates to mechanisms that define what problems are to be pursued, how they are to be tackled and which results shall count as valid. This involves a shift from control located within disciplines to more diffuse kinds of control that reflect the transdisciplinary nature of the problems being addressed. In Mode 2, success is defined differently from that in Mode 1. Success in Mode 1 might perhaps be summarily described as excellence defined by disciplinary peers. In Mode 2 success would have to include the additional criteria such as efficiency or usefulness, defined in terms of the contribution the work has made to the overall solution of transdisciplinary problems. In both cases success reflects a perception of quality as judged by a particular community of practitioners. But, all quality control is linked, legitimated and, ultimately, receives its credibility and scientific authority from an idea, image, or concept of what constitutes good science including best practice. For example, at different times in history what constitutes good science has been guided by the ideal of truth and the search for unitary principles. In Mode 2, the issue of assessing the quality of good research is twofold. One has to do with the fact that the community of practitioners is transient and transdisciplinary, as we have already shown, the other arising out of the fact that the criteria of quality are not solely those that obtain in Mode 1 but include the additional criteria that arise out of context of application.

Currently conventional wisdom is that discovery must precede application. Although this has not always been the case it has provided a powerful image of how things ought to be. By contrast, Mode 2 quality control is additionally guided by a good deal of practical, societal, policy-related concerns, so that whatever knowledge is actually produced, the environment already structured by application or use will have to be taken into account. When knowledge is actually produced in the context of application, it is not applied science, because discovery and applications cannot be separated, the relevant science being produced in the very course of providing solutions to problems defined in the context of application. Those who exert quality control in Mode 2 have learned to use multiple criteria not only in general, but in relation to the specific results produced by the particular configuration of researchers involved.

The Dynamics of Mode 2 Knowledge Production

In order to understand better the growth and diffusion of Mode 2 a distinction will be drawn between homogeneous and heterogeneous growth. Within the scientific enterprise an example of homogeneous growth would be the expansion of a given entity, say papers in nuclear physics, where the rate of growth often follows a logarithmic curve. In this case, growth essentially consists of the production of more of the same, whether these are numbers of papers produced or numbers of scientists working in a given field. The result is exponential growth which would continue indefinitely were it not for the fact that resources are finite (De Solla Price, 1963). Heterogeneous growth, by contrast, refers to a process of differentiation through which rearrangements of component elements take place within a given process or set of activities. In these cases it is the number of rearrangements that grow rather than solely the number of outputs, that is, a shift in the pace of internal differentiation occurs. Considering only national research and development (R&D) statistics in the aggregate, or listening exclusively to the rhetoric of the institutional leaders of the scientific community, may mask the phenomenon, but it is evident that deep-seated structural changes are taking place in the relationships both within and between the scientific communities and society at large, with knowledge becoming socially distributed to ever wider segments of society. The globalisation of science and R&D sourcing and the role that specialised knowledge has come to play in technological innovation result in a highly differentiated, heterogeneous form of growth of knowledge. This is expressed tellingly in authorship patterns of scientific papers, the traditional vehicle of scientific communications. Not only is the average number of authors per paper increasing, but much more significantly, so are the diversity of specialisms and disciplines involved in the writing of a single paper and the range of institutions and organisations from which the authors originate. In addition, the geographical distribution of these institutions continues to broaden. In Mode 2, not only are more actors involved in the genesis of knowledge but they remain socially distributed.

What kind of model, or analytical framework, might best describe this process of heterogeneous growth, a process of diffusion in which the numbers of linkages between entities increases and new configurations are set up, which dissolve and re-emerge in different combinations? Communication plays a central role in this process and the density of

communication appears to be the key variable. An increase in the density of communication is an indication that the rate of diffusion is increasing, and given a multitude of different sites of knowledge production and sufficient diversity among participants, growth is likely to be heterogeneous rather than homogeneous.

During the past decades most industrial countries have been putting in place the basic infrastructure for a dynamic knowledge production system based upon specialisation and disciplinary structures. This has involved building up many more universities and research centres of various kinds, often through government research contracts and procurement, encouraging corporations to become significant performers of R&D. Investments in this pattern have established not only a flourishing research culture but also have vastly multiplied the number of sites at which scientific research could be conducted, not only within particular nations but world-wide. In an unplanned and unforeseen way these past investments have established the essential preconditions for the numbers of communication linkages to become large enough to change existing patterns of knowledge production in a fundamental way. The density of communication between the elements of the global research system has reached the criticality which makes a significant expansion of communication linkages a certain, though unintended outcome. The expansion of the number, nature and range of communicative interactions between the different sites of knowledge production leads not only to more knowledge being produced but also to more knowledge of different kinds; not only to sharing of resources, but to their continuous configuration. Each new configuration becomes itself a potential source of new knowledge production which in turn is transformed into the site of further possible configurations. The multiplication of the numbers and kinds of configurations are at the core of the diffusion process resulting from increasing density of communication. Its precondition is the vast increase in the numbers of communicative interactions of many kinds, because only a fraction of these will result in new configurations, which are sufficiently stable to become sites for further knowledge production. This process has been greatly aided by information technologies which not only speed up the rate of communication, but also create more new linkages.

The expansion of the numbers of communicative interactions which underlies the notion of the density of communication includes communications which take place within a particular specialism as well as those which take place between specialisms. Functionally, as well as in its historical evolution, the increase in density rests upon an interrelated three-tiered system, where each level depends upon the other two. In the production of scientific knowledge communication occurs between science and society at large, among scientific practitioners and also with entities of the physical or social world.

Communication between science and society This is the widest, and by the very nature of the communication link, the most loosely linked web of communication. Traditionally, communication between science and society was essentially one-way: scientists were the holders of privileged expert knowledge, while the lay public was to be enlightened and educated. In the past various forms of popularisation of scientific knowledge have shaped this relationship, without altering the basic underlying conception. The pressure for increased accountability arises in two distinct but related ways. First, in all countries there is now much greater pressure to justify public expenditures on science. Financial accountability is essentially about justifying expenditure, about ensuring that financial resources have been spent in the manner stipulated in the allocation process. But, second, this is only one aspect of a much broader social concern with the conduct and goals of scientific research. There has been an increased demand for social as well as financial accountability.

Enhanced social accountability, particularly evident in the last few decades, arose as a better educated citizenry placed new demands on science. These demands were nurtured against the background of a number of techno-political controversies. In the public debates around these controversies it became obvious that a strong requirement for social assessment of science and technology had taken root in society. The previous one-way communication process from scientific experts to the lay public perceived to be scientifically illiterate and in need of education by experts has been supplanted by politically backed demands for accountability of science and technology and new public discussions in which experts have to communicate a more 'vernacular' science than ever before. The most sensitive domains so far have centred upon technological risks, notably those connected with nuclear power and other hazardous large technical facilities, environmental concerns covering a wide range of topics from the ozone layer to biodiversity, and potential dangers or ethical issues associated with biotechnology and genetic engineering. In all these cases, technology has perhaps been more implicated than science per se, while in the mind of the public the two are seen as closely intertwined. What is at issue very often is the claim that research knows no limits – with the counterargument asserting that not everything research can learn or do, should actually be learned or done, nor is it always beneficial to society. A related argument is that it is no longer possible to contain scientific and technical experiments in the laboratories properly speaking and that society itself has become a laboratory for experiments that ought to be controlled in a more societal and tighter way.

The new demands for accountability and for more communication between the community of scientific and technical experts and the 'attentive' public are interconnected and emanate from the spread of higher education through society. The increased level of education of the

population in highly industrialised societies, and the widespread use of technological applications in households, workplaces and in other public (for example, transport) and private (for example, health) places all accelerated the wide diffusion of scientific and technological knowledge into society. As many detailed studies of market-oriented technological innovation have shown, the presence of potential buyers and users directly in the contexts of development influence the direction that innovative lines of research will take (Von Hippel, 1976, 1988).

New forms of knowledge production can, as they diffuse, make for ambiguous situations as older demarcation lines and boundaries become more porous or break down altogether. For example, universities can adopt 'values' from the corporate culture of industry, bringing forth an entirely new type of academic entrepreneur. Conversely, big firms adopt some of the norms of academic culture, for example when they give employees sabbaticals or provide other forms of training possibilities. On a broader level, intellectual 'property rights' have become a major issue on the campus, thereby giving new roles to the lawyers rather than committees in resolving conflicts and in regulating the conditions under which research is performed. The list of examples can be extended almost indefinitely. Through what mechanisms do such 'borrowing' or transfers of norms and practices occur, and how does each subsystem maintain its distinct identity and founding values according to which it resolves other conflicts?

The mixing of norms and values in different segments of society is part of a diffusion process which at the same time fosters further communication among them by creating a common culture and language. In addition, a variety of inter-systemic agencies or intermediary bodies establish themselves in the interstices between established institutions or their components; examples from the United States might be the Occupational and Safety and Health Administration, or the Friends of the Earth, a governmental agency and a private organisation respectively, both concerned with environmental quality, both crossing disciplinary lines and both involving public, private and scientific interests, people, resources and powers. Thus while different kinds of institutions are able to maintain their own distinctive character and functions, they continually generate new forms of communication to link them together. This partially explains the emergence of new hybrid communities, consisting of people who have been socialised in different subsystems, disciplines or working environments, but who subsequently learn different styles of thought, modes of behaviour, knowledge and social competence that originally they did not possess. Hybridisation reflects the need of different communities to speak in more than one language in order to communicate at the boundaries and in the spaces between systems and subsystems. The availability and willingness of large numbers of people to become members of such hybrid communities, however, is also due to the spilling over of scientific attitudes,(which we have loosely defined as a greater readiness to ask questions, and to seek answers through reason, and evidence and the acceptance of change in general), from universities and laboratories to society at large.

Thus, communication between research and society increasingly takes the form of diffusion processes that carry scientific and technological knowledge into society while social norms and expectations held by different institutions and communities are brought home more forcefully to the research communities. At the same time, the sites in which knowledge is created proliferate, increasing both the possibilities and the need for such diffusion. Communication becomes more dense in line with the evolution of overall societal complexity.

Communication among scientific practitioners Scientific communication linking the sites of knowledge production is carried through the flows of scientists and scientific ideas among them. The density of communication among scientists is embedded in the social organisation of their work. It was realised at the beginning of modern science that a division of scientific labour would be a crucial factor in speeding up the solution of scientific problems. Already in the sixteenth century, Kepler had remarked upon the division of labour among the astronomers of his time: if they were more numerous they would not only be able to gather more observational data, but also by applying their scientific work to a few highly selected problems, they could contribute more efficiently to solution of the problems.

Communication among scientists is influenced by two factors: one is their mobility, while the second relates to how they set priorities and select problems. Mobility, is an essential precondition for the cross-fertilisation of scientific ideas and know-how. Scientists moving between different sites of knowledge production exchange ideas and know-how, and learn about new techniques, devices and principles. Numerous instances of scientific creativity, of sudden insights and the opening up of novel pathways towards solutions can be traced to encounters between scientists brought together from different sites. The more mobility a science system permits or even encourages, the more potential instances of this kind can be expected.

Of course there are limits to mobility as well, imposed by the necessary balance between stimulating fresh insights and the laborious process of working them out. But it is obvious that the density of communication among scientists through various forms of mobility has been greatly increased in recent decades. Numerous conferences and meetings are complemented by a wide assortment of different communication channels, ranging from the old-fashioned article to pre-prints, from phone to fax to

electronic mail and multiple networks that allow many minds to meet and discuss issues together without being physically present in the same place. And it is not irrelevant that the world-wide network of electronic mail is heavily subsidised by governments, making its use essentially free to its users.

The multiplication of both formal and informal communication channels has meant a stupendous growth in the density of communication. As recent examples, from the initial news about the discovery of high temperature superconductivity or the alleged success in achieving cold fusion show, the scientific community displays all the features of a global village. Almost instantaneous communication offers scientists working even in remote places the possibility of duplicating experiments immediately, drawing in new experts and exploiting novel ideas. The sheer range of possibilities for new forms and intensities of communication also opens up, at least in principle, the growth of communication between different specialisms, an important aspect of Mode 2 knowledge production. While in the past scientists were more limited in the means of communication at their disposal and used them mainly to communicate within their own specialities, modern information and communication technologies provide them with a widened spectrum of opportunities.

Transdisciplinarity has been facilitated through the availability of these enhanced means of communication. The computer itself has become the new and powerful tool in science which generates a new language and images. One can cite the beautiful coloured images of fractals that have changed the perception of scientists and the general public in ways that are both aesthetically pleasing and mathematically challenging. Modelling data, whether related to environmental research where huge climate or ocean flow models are being generated, or within geography and related disciplines where the advent of geographical information systems (GIS) have literally changed the way of seeing and practising regional planning, have opened new channels of communication cutting right across scientific disciplines and fields of research. Through the inclusion of images and other modes of representing data, an entirely artificial world of representation continues to be created, attesting to the powerful creativity of these new forms of scientific communication. All aspects of Mode 2, and especially transdisciplinarity are increasingly strengthened through these new modes of representation that cut across disciplines while greatly adding to the density of communication with nature and among scientists.

The second factor affecting the increased density of communication among scientists and their research sites arises out of the ways they select problems and set priorities. It is obvious that not all problems deemed worthy of investigation will actually be studied by a critical mass of scientists large enough to make a difference. Characteristic differences in the ratio of people to problems exist between disciplines and specialities.

This allows Becher to compare the 'urban mode' of communication, which he sees as characteristic of the hard sciences with a 'rural mode' which is characteristic of the soft sciences (Becher, 1989: 79–80). As in an urban area, the cognitive territory in the former case is densely packed and crowded by people who all want to work on a small number of problems which are thought to be highly relevant and rewarding. The cognitive space is therefore crowded, communications thick and competition intense. By contrast, many, though not all of the soft sciences and practically all of the applied sciences seem to be marked by a 'rural' form of communication. Problems considered worth working on are much more numerous and widespread; scientists have a lot of choice, and can settle in the next valley if they think the current one is already overcrowded. Communication patterns are less well organised, and news about significant conceptual or methodological advances trickle down rather than spreading rapidly. Hence scientists working in an urban mode must have established mechanisms that allow them to agree more easily on the problems. It is then possible to delineate a more or less common frontier of knowledge and to speak about the kinds of problems that everyone would expect to be relatively near solution, with others perceived to be still further away in the future. A 'rural' mode, by contrast, would also entail a slower pace of collective scientific advance, more dispersed intellectual resources and also with individualistic ways of working. Density of communication between scientists is therefore an important factor in accelerating knowledge production, not just across a variety of different sites, but also on a single, heavily populated site, where problem space is scarce and the price of cognitive territory correspondingly high.

Another important factor in the patterns of communication between scientists relates to the international and local or national dimension. The way that impinges upon competition and cooperation among scientists and the kinds of issues that arise for research organisations still largely embedded in national systems, will be described in a later chapter. Here, it will suffice to re-emphasise that communication among scientists is both essentially international, in line with the universalism of science, and locally or nationally-oriented, in line with the still dominant national orientation of R&D funding. The career structures of scientists, their international mobility notwithstanding, are still largely shaped by the national science system; hence the perpetuation to some degree of different national styles or national traditions of knowledge production.

Communication with the entities of the physical and social world

Communication in this sense is a metaphorical way of describing how scientists approach the object of their study. Ever since the beginnings of modern science in the seventeenth century, ideas about how to 'make nature speak', how to 'induce her to reveal her secrets', or even ways to

'force her to answer' have been used as a way of describing, the experimental set-up and the preconditions framing it. From Galileo's time onwards, the main and most successful language to be used in communicating with nature has been a formalised discourse using mathematics and other kinds of formalised symbols. However, the scientific-conceptual side of this dialogue has always been matched by a forceful communicative practice of attempts at manipulation and control. The practical side of experiments entails craft-work, skills, knowledge and, of course, instruments and technology.

What, then, has changed between the beginnings of modern science and the hi-tech forms of communication with nature that dominate science today? Science has made it possible to observe, analyse and partly to manipulate the 'very large and the infinitesimally small' as exemplified by experiments conducted in space on, say, gravitational waves or the first steps of manipulating individual atoms on the microscopic level of matter. In any laboratory, nature is not just present, but has to be brought in. Then and there, nature is thus appropriately prepared, and can be deliberately subjected to experiments. Through proper preparation it has become possible to speed up or slow down processes, to enlarge or miniaturise according to experimental design. In doing so, instrumentation has been the indispensable working tool, while being far more than merely a piece of technology. Scientific instruments embody scientific knowledge while leading to the generation of further scientific knowledge. They are looked upon, correctly, as a major source of scientific innovation, while often providing important core elements to engender also further technological innovation, once they are transferred from the laboratory to other sites of knowledge production. In short, on the level of communication with nature there has been a stupendous growth of techniques, sophistication of concepts, instruments and tools that have increased the richness of the language in which scientific communication is carried out. The modes of speaking have matured and increased. The experimental sciences not only use symbols, such as those of mathematics, but an array of new devices and instruments, such as STM, the scanning tunnelling microscope or other experimental practices of an empirical kind to achieve this end.

The field sciences such as parts of biology or geology that cannot rely on experiments, have had to develop other methods to converse with nature, while still relying on carefully compared, dated and assessed empirical evidence of fossil records and of geological strata, mineral deposits, plant life and the like. They, too, seek a form of communication with nature, where nature is ready to tell its history in all its details and local variations. Here, too, new instruments and methods, such as the greatly increased sophistication of dating methods for geological and fossil samples, have opened up new possibilities for asking ever new questions. At present, scientists have begun, for instance, to work systematically on the environmental history of the earth. Paleoclimatology seeks to unravel the major changes in climate conditions the earth has lived through and under what conditions they occurred. In making the earth speak, so to speak, and tell its own history in terms relevant to the understanding of today's environmental stresses, implies a combination of methods and models, of observational data and measuring methods for inference, that taken together provide a new degree of communication density in working towards such goals.

These examples from the experimental sciences and the field sciences show that communication is not a phenomenon limited to the social sciences and the humanities. Social scientists also attempt to make their subjects speak, while historians are well aware that the reinterpretation of history never ends. In the humanities, a philosopher such as Derrida (1976) claims that the text can be made to speak for itself and even against itself. In all these cases, meanings and interpretations are involved. Elements from the past, as in history, or from a text, as in literary criticism, are chosen self-consciously and critically, in view of present theoretical or social relevance and future-related significance. Communication with nature or with society is never an end in itself. It remains linked to the interests and social practices of those who communicate.

All sciences, however, have to develop methods and check their interests to prevent nature or its analogue telling them only what they, the scientists, want to hear. They have to make sure that communication remains authentically communicative: in the sense that not all possible interpretations or answers are acceptable, but only those that have been carefully safeguarded against scientists hearing their own voices in a kind of echo effect. When they practise science, scientists behave as realists. They believe that some kind of reality exists out there, with which they have established a suitable form of communication not only verbally or conceptually, but in a robust, technical sense as well. If we accept that scientific theory and practice are intrinsically underdetermined with regard to a reality supposed to exist out there, we can begin to appreciate how much society must be present to constitute the language that allows the filling of the interstices and gaps in this dialogical form of communication with nature. The more sophisticated and complex society becomes, the more dense will be the content and form of the dialogue with nature. A highly developed and technologically sophisticated science, therefore, can produce ever denser forms of communication.

To continue the metaphor, communication with nature is impregnated with social syntax, semantics and technological pragmatics. It can spread if local sites in which this form of communication can be practised multiply, as it is likely to do when the number of scientific practitioners, that is competent speakers, increases. But any form of communication is not

primarily quantitative, but a complex qualitative phenomenon. The richness of any communication does not depend primarily on how many words are used, but which ones and in which context. And since communication is essentially open-ended, it allows not just for one, but for an increasing number of possibilities of expression and representation, depending upon the specific characteristics of each site and context. A well developed language allows one to say (almost) everything; hence, the open-ended nature of scientific advance. But no language, no form of communication, can be uncoupled or disembodied from speakers and from the speech events they create. Language, and any form of communication, remains highly context specific, since semantics, the attribution of meanings, is an inherent feature of communicating. The greater the ability to master a language the more attention has to be paid to the context in which communication occurs. If everything can be said, it also becomes obvious that not everything is, or in fact, will be said. Hence, priorities and selection mechanisms will be established intentionally or unintentionally. If the local sites of communication with nature are multiplied progressively, questions of what is being produced there begin to matter.

Some Congruent Substantial Innovations

The dynamics of Mode 2 knowledge production that we have characterised in terms of the fruitfulness of the contexts of use and application, and by renewed channelling of exchanges and patterns of communication, is not just a matter of form or process. It is also a matter of substance or content, as Mode 2 is practised at the frontiers of some techno-scientific research. The more important among these substantial matters include: the widespread recovery within science of an interest in concrete and particular processes and systems rather than in general, unifying principles; the search for knowledge through design whether in physical or biological systems; the constitutive role of computational models in the intellectual and experimental behaviour of scientists and technologists.

The recovery of interest in specific, ordered structures There is occurring a profound and widespread shift in the rationale of scientific enquiry. Modern science, in its first phase, was characterised by the search for first principles; for example, the search for an abstract mathematical formulation of the rules governing the motion of matter in space and time. In this, Newtonian physics was triumphant and provided the first, highly successful exemplar of what science ought to be. However, it seems that nature is more subtle than is allowed by models of mathematical physics and, as empirical method diffused, so science has relaxed, but not abandoned, its search for first principles and devoted itself more and more to trying to understand natural phenomena and processes using whatever

Ideas, techniques and methods would yield that understanding. The use of increasingly sophisticated technical means to explore the world, that is to collect data, and using this to test a wide range of intellectual structures is an example of this trend. This expansion of the technological means has made possible a vastly more sophisticated analysis and has allowed the diffusion of many of these techniques from one discipline to another. This is well illustrated by the history of nuclear magnetic resonance which diffused from physics through chemistry to biology and to its current use in medical diagnosis. This approach to nature has been extremely fruitful of ideas and discoveries as well as of practical applications and does not seem to have been much delayed by the failure to find a set of first principles in nuclear science. On the contrary, it has produced a growing awareness of the power and range of empirical methods which have supported a growing interest in the concrete and the particular. This shift may be seen not only in the gradual replacement currently of physics by biology as the exemplar of science but, more generally, in the abandonment of any ideal to which all sciences ought to aim. Instead, there is a pluralism of approaches which combine data, methods and techniques to meet the requirements of specific contexts.

Knowledge through design One consequence, related to this general concern with understanding specific, ordered structures, is the intention to use this understanding to predict and control their operation in specific conditions. While the production of knowledge with practical ends in mind has always occupied an important place alongside gaining a better understanding of the physical and social world, continuous innovation through applying scientific and technological knowledge in different contexts has reached a new level. The bio-sciences, materials science and computer and information science, for instance, are now structured with a ... d interest in application in mind. The current search for the architecture o... fifth generation computers lies behind, or in front of, much of the current research into very large scale integration of electronic switches, and no small amount of the physics of semiconductors or the mathematics of fuzzy logic. While many of the problems in these areas possess an intrinsic intellectual interest for those who work on them, this interest is also continuously nourished by research and practical interests of other users as can be seen in genetics, electronics, mathematics and physics. Rather than pushing science into intellectually sterile backwaters, as was once feared, the expansion into ever new contexts of application provides attractive and challenging environments. A reiterative intellectually fertile exchange of concepts, methods and instrumentation continues to widen our understanding of both natural and artificial phenomena, and with it the possibilities of manipulating and controlling them.

One important aspect of this still early development, is that it has

become possible to reverse the conventional procedures for making certain substances such as molecules, chemicals and materials. Instead of purifying natural substances or resorting to complex reactions to obtain those with the desired properties, the required materials can now be built up atom by atom, or molecule by molecule, by design, in order to obtain a product with specified properties and possessing certain desired functions. It therefore has become feasible to design a far greater range of materials than previously; the prospect of sciences completely devoted to fabricating artificial materials in this way has become possible. In this regime the product and the process by which new materials are made become integrated in the design process, including specific uses and functions the product is intended to fulfil. Fabricating processes becomes more efficient not only in terms of costs but more importantly, in terms of reduced adverse environmental impact while opening up an entirely new range of possibilities (as claimed especially by the proponents of 'artificial life').

Computational modelling Since both the design of specific materials and their fabrication are increasingly controlled by computers, this opens the way to developing routines that are independent of particular applications and can be used to meet a wide variety of needs. The design and production of a new generation of advanced materials are therefore critically dependent on information technology. This highlights the importance of information technology (IT) infrastructure and communications in the whole research process and the emergence of a science and technology based upon computations. The experimental process with its underlying trial and error approach in the empirical world, is increasingly complemented, if not in part replaced, by new computational models of simulation and dynamic imaging.

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2
The Marketability and Commercialisation of Knowledge

Summary

In Mode 2, knowledge production becomes part of a larger process in which discovery, application and use are closely integrated. One important mechanism by which this happens is the expansion of the market for knowledge and the increased marketability of science (and not only of technology). The driving force behind the accelerated supply and demand of marketable knowledge lies in the intensification of international competition in business and industry. In many cases in-house research is no longer sufficient to meet competitive demands. In order to commercialise knowledge, firms have to look for new types of links with universities, government laboratories as well as with other firms. In this chapter we explore some of the parallels between industry's search for economies of scale and of scope and the production of scientific and technological knowledge by research organisations. In both cases intensified competition is at the centre of the demand for specialist knowledge. The combination of economies not only of scale but of scope with dynamic competition shifts the locus of added value in the innovation process, involving firms more closely in Mode 2 knowledge production.

Economies of scale also apply to knowledge production in the academic and government research system especially where large, sophisticated technological systems and rational techniques of management are involved. But comparatively little investment and concern has gone into distributing the results of research which transcend the communities of specialists that these laboratories serve. This institutional separation of production and distribution has created the very language of knowledge transfer as well as attempts to move research oriented institutions closer to the marketplace and to the public sector. But as long as the norms and rules governing Mode 1 knowledge production

prevailed and as long as it was believed that whatever item of technology which entrepreneurs wanted would be available as a stream of inventions, the incentives to encourage the diffusion of research could be ignored. The situation changed because research costs rose more quickly than inflation as a result of the familiar sophistication factor. Research budgets came under chronic strain. The use of research for economic purposes has again moved into a central position in the science and technology policies of many countries, although it is often overlooked that in many advanced sectors of science and technology, knowledge is already created in the context of application.

Next we explore the role that competition plays in the generation of knowledge. We maintain that this role is not widely understood. Firms that wish to compete in the international marketplace are confronted with competition as a dynamic process, meaning that later decisions and investments are constrained by prior ones and therefore can either not be reversed or only at a high cost. Moreover, the criteria of admittance to the competitive game change in novel ways. Collaborative ties come to play an increasing role in the way actors behave. Finally, the rules governing competition evolve according to the enabling capacities of new technologies. The traditional concept of competition rules out the possibility that rivalrous behaviour can have beneficial effects for individual firms. Operating the new dynamically competitive environment means working with regimes of knowledge production similar to Mode 2, which are based on both competition and collaboration and on the ceaseless reconfiguration of resources, knowledge and skills. Firms are required early on to choose particular design configurations as well as associated dominant competences which are embodied in the creativity of its scientific and technological workforce and in the infrastructure of the particular firm. The ultimate success of the firm depends on the potential of this creativity and infrastructure in response to market demand. Collaborative relationships are welcome because firm-specific knowledge accumulation (as well as capital investment) is dependent upon a larger, possibly global, environment in which knowledge is being produced (and capital invested in research).

In the final section of this chapter we take a closer look at changes in the organisation of production and distribution of technologies that have sustained continuous economies of