Knowledge Management in the Learning Society

EDUCATION AND SKILLS

OECD

CENTRE FOR EDUCATIONAL RESEARCH AND INNOVATION

KNOWLEDGE MANAGEMENT IN THE LEARNING SOCIETY

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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FOREWORD

A new and challenging task of the OECD is to contribute to the understanding of knowledge and learning in the context of economic development and social cohesion. This book is an ambitious attempt to do so. Although it presents a preliminary overview of the knowledge processes at work in different sectors, the book identifies a number of ways in which micro-level or sectoral understanding of the knowledge-based economy is important, alongside the more macro-level insights. These insights are valuable for governments, economic sectors, and public and private enterprises and institutions when they are seeking to improve their knowledge and learning performance, which is increasingly important in order to function in a learning society. Special attention is given to how to improve the production, mediation and use in the education sector. The need for improvement in this sector seems particularly urgent if the traditional education system is not to be marginalised in the emerging knowledge-based society.

This book is in two parts. Part I constitutes an important, enlightening conceptual piece of work on issues concerning knowledge and learning in an economic innovation context. A comparative study of the production, mediation and use of knowledge in different sectors has been undertaken to achieve two purposes: first, to illuminate the general nature of these processes in modern economies; and secondly, to clarify how the education sector manages knowledge and how it might improve it. Finally, some ideas are presented on a new research agenda that could help to improve our understanding of knowledge and learning. Part II of the report brings together a rich selection of the principal expert papers on knowledge production, transfer and application in different sectors from the four below mentioned forums.

The analyses presented in this book derive from four forums that have been organised with high-level participants from the private sector, policy-makers, academics from a wide range of disciplines and authorities in health and educational research – all of whom are working on issues and problems related to how knowledge and learning will become key drivers of social and economic change in the coming century. The aim of these forums was to explore how knowledge processes can be identified, analysed, compared and measured in the engineering, information technology, health and education sector. The *first* one took place in Tokyo in November 1997 and was jointly organised by the OECD, the Japanese Ministry of Education, Science, Culture and Sports and the Japanese Society for the Promotion of Science. It dealt with "Knowledge Production, Mediation and Use in Industry-University Settings: The Engineering Sector". The *second* was on "Production, Mediation and Use of Knowledge in the Education and Health Sectors" at OECD in Paris in May 1998. The *third* was organised in co-operation with the Graduate Business School at Stanford University on "Knowledge Production, Mediation and Use in Learning Economies and Societies" at Stanford University September 1998 with a particular focus on the role of information technologies in knowledge processes. Finally, the *fourth* forum was jointly organised by the OECD and the US National Science Foundation on "Measuring Knowledge in Learning Economies and Societies" in Washington DC in May 1999. In Tokyo and Stanford, the forums were combined with visits to leading knowledge-intensive companies.

This publication results from a collective effort by consultants and the CERI at the OECD. The project was sponsored by the US National Science Foundation. Professor Jean-Michel Saussois, École Supérieure de Commerce de Paris, France, and Principal Administrator Kurt Larsen, CERI/OECD, have been responsible for conceptualising and managing the project. Part I was principally prepared by Professor Bengt-Åke Lundvall, Aalborg University, Denmark (Chapter 1) and Professor David Hargreaves, Cambridge University, United Kingdom (Chapters 2 and 3). Part II was edited by M. Saussois. This book is published on the responsibility of the Secretary-General of the OECD.

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Part I

KNOWLEDGE MANAGEMENT IN THE LEARNING SOCIETY

Chapter 1

UNDERSTANDING THE ROLE OF EDUCATION IN THE LEARNING ECONOMY: THE CONTRIBUTION OF ECONOMICS

Introduction

Education systems must meet new expectations, and face new competition…

Education systems are under constant pressure, on two main fronts. First, they need to adapt to changes in society, which, as it becomes a learning society, has rising expectations for education. Second, the school as a "house of knowledge" is increasingly facing competition from other knowledge sources, including information and entertainment, and from enterprises that define themselves as knowledge producers and mediators.

… by adopting distinctive roles in knowledge-oriented societies, by learning to work smarter, using knowledge that is not always "scientific"…

Schools and other educational institutions thus face a double challenge for dealing with knowledge and learning. First, can education, and those with expertise in education, define a new role for schools in building and servicing a "knowledge-based society" or will that society marginalise them? What functions can schools legitimately fulfil in the emerging learning society that would not be better fulfilled by other actors and institutions? What innovations are needed if they are to perform them? The second challenge is the need for high performance and the capacity of the school system to adapt to meet the challenges that will continue to arise. Given a definition of their new mission, means of continuously improving the performance of schools will have to be developed. Unlike spheres such as medicine and manufacturing, education has not seen continuous and clear improvements due to technical and organisational advances. Is it possible to harness research and other forms of knowledge more effectively in this sector? Or is education rather an art so strongly rooted in practical experience that establishing a systematic, "scientific" knowledge base for its activities would be irrelevant? These are the central issues of the discussion that follows.

… and by looking at how other sectors produce, use and mediate knowledge.

In this project, these fundamental questions are illuminated by means of a comparative analysis. Education is compared with other sectors – health, engineering and information technology – as regards the production, mediation and use of knowledge. In this first chapter, three different themes are introduced: first, basic concepts related to knowledge and learning; second, the contribution of economic analysis to the understanding of the production, mediation and use of knowledge in different sectors; and third, new economic trends and the formation of a "learning economy" and the issues raised for schools.

Knowledge is becoming the core element driving economies; yet it remains hard to understand, measure or systematise its contribution…

This project is based upon the assumption that our societies are undergoing a transformation as important as the industrial revolution that began more than two centuries ago. Knowledge is the core element in the emerging mode of production, and learning is the most important process. Yet our knowledge of how knowledge is created, transferred and used remains partial, superficial and partitioned in various scientific disciplines, with the result that the basic concepts of knowledge and learning are defined and interpreted in different ways. The indicators used to measure knowledge and learning are correspondingly weak. It is fair to say that we have not yet reached a stage where we can systematically apply knowledge to the production of knowledge. As we shall see, this is true for schools, as there is little systematic scientific understanding of what goes on in them. It is equally true for the learning taking place within firms and in society. The real breakthrough of the industrial revolution occurred when machinery was used to produce machinery. It is tempting to see an analogy: the full-scale transformation into a learning economy will have to await the systematic application of knowledge to the production of knowledge.

... at the same time it is essential to address the key role of knowledge and learning in wider social and cultural life.

A major task of the OECD as a whole is to contribute to the understanding of knowledge and learning in the context of economic development and co-operation. The fact that learning also shapes the life of citizens in OECD countries in many other respects, such as citizenship and family life, must be taken into account. To play an active part in society and in local, national and global politics, general skills related to one's mother tongue, foreign languages, mathematics and information technology become increasingly important. Even coping with the challenges of daily life is becoming more demanding in these respects and in relation to sharing a cultural heritage. The more irregular careers of individuals and the frequent changes in their relative position in local and national communities increase the need for understanding culture and for insights and values that make change understandable and bearable. Thus, while understanding the role of knowledge and learning in relation to the economy is fundamental, it is equally important to take knowledge and learning in its broader societal and cultural context into account.

A terminology of knowledge

Is *knowledge a public or a private good*?

There is no commonly accepted system for describing or classifying knowledge...

In 1987, Sidney Winter concluded a paper on knowledge and management strategy by pointing out that there is "a paucity of language" and "a serious dearth of appropriate terminology and conceptual schemes" for analysing the role of knowledge in the economy. Since then, the number of relevant publications has grown immensely, but little headway has been made in terms of a terminology acceptable to all. There is little agreement on questions such as: What is the meaning of knowledge and knowledge production? What separations and distinctions between different kinds of knowledge are most useful for understanding the interaction between learning, knowledge and economic development?

... economists need to find ways of distinguishing different types, that also make sense outside economic discourse.

When proposing terminology and a conceptual scheme, it is essential to aim at one that fulfils two different requirements. First, it should help to distinguish between different ways of treating knowledge in economic theory. Second, it should have a certain intuitive connection to what is meant by knowledge in broader public discourse so that it is possible to communicate with non-economists.

Economic models see knowledge first in terms of gathering and processing information needed to make choices...

Knowledge and information appear in economic models in two different contexts. The most fundamental assumption of standard microeconomics is that the economic system is based on *rational choices made by individual agents*. Thus, *how much and what kind of information* agents have about the world in which they operate and how powerful their *ability to process the information* is are crucial issues. This perspective on knowledge puts the focus on a transformation process whereby data (the actual state of the world) can be transformed first into information (indicators that are accessible to the agents representing the state of the world) and then into knowledge (through the processing the information in analytical models by agents).

... and second as an asset that contributes to production through competence and innovation.

The other major perspective is one in which knowledge is regarded as an *asset*. Here, knowledge may appear both as an input (competence) and output (innovation) in the production process. Under certain circumstances, it can be privately owned and/or bought and sold in the market as a commodity. The economics of knowledge is to a high degree about specifying the conditions for knowledge to appear as "a normal commodity". Innovation theory and competence-based theories of the firm address how knowledge can be produced, mediated and used in a market economy.

This latter sense is of greater general interest, and is central to this report.

In what follows, attention focuses on knowledge in this latter sense, principally because this perspective gets closest to the concerns of non-economists and education experts. It raises the issue of how knowledge – in terms of competence and innovation – is produced, mediated and used. It is also helpful for making distinctions between generic and specific knowledge and between different forms of learning. The first perspective, important as it is for understanding how economic decisions are made, is somewhat more closely tied to the discipline of economics.

Two key issues are whether knowledge is public or private, widespread or local:

In analysing knowledge as an asset, its properties in terms of transferability across time, space and people are central. This issue is at the core of two different strands of economic debate. One is the public/private dimension of knowledge and the role of government in knowledge production, the second the formation of industrial districts and the local character of knowledge.

Where knowledge is publicly available, markets may not result in optimal levels of its production...

Is knowledge a private or a public good? In economic theory, the properties that give a good the attribute of "public" are the following: *i*) their benefits can be enjoyed by many users concurrently as well as sequentially without being diminished; *ii*) it is costly for the provider to exclude unauthorised consumers. It is important to note that this does not imply that these goods should be supplied by the state, that a market for public goods will not exist, or that private provision of these goods is impossible. However, in the absence of public intervention, there may be an economically inefficient allocation of resources to the production of those goods.

... because private agents lack incentives to invest, creating a case for public funding...

The reason for the interest in this issue is that it is crucial for defining the role of government in knowledge production. If knowledge is a public good that can be accessed by anyone, there is no incentive for rational private agents to invest in its production. If it is less costly to imitate than to produce new knowledge, the social rate of return would be higher than the private rate of return and, again, private agents would invest too little. The classical contributions by Nelson (1959) and Arrow (1962*b*) demonstrated that, in such situations, when the knowledge produced is public or semi public, there is a basis for government policy either to subsidise or to take charge directly of the production of knowledge. Public funding of schools and universities, as well as of generic technologies, has been motivated by this kind of reasoning, which also brings to the fore the protection of knowledge, for instance by patent systems.

... but conversely, the local character of much knowledge can make it difficult to share, and its dissemination becomes the problem.

In a sense, this fundamental problem remains at the core of the economics of knowledge production. However, another strand of thought, with roots far back in economic theory, has become more strongly represented in the debate in the last decades. It is the question of how to share knowledge that is difficult to mediate. Marshall was concerned to explain the real-world phenomenon of *industrial district*: why it was that certain specialised industries located in certain regions and why they remained competitive for long periods. His principal explanation was that knowledge was localised in the region and rooted both in the local labour force and in local institutions and organisations. This perspective, with its focus on localised knowledge, has, in the light of Silicon Valley, resurfaced strongly among industrial and regional economists over the last decades. Correspondingly, the management literature has seen a growing interest in knowledge sharing within and between firms.

In both cases, it becomes important to understand how knowledge is transferred and mediated, which in turn depends on its characteristics, explored below.

These two perspectives, while seemingly opposed in their contrasting emphasis on protection and sharing of knowledge, raise the same fundamental questions. Is knowledge public or private? Can it or can it not be transferred? Is the consent of the producer needed for the mediation to be successful or can knowledge be copied against the will of the producer? How difficult is it to transfer knowledge and what are the transfer mechanisms? Is it possible to change the form of knowledge so that it is easier (more difficult) to mediate? How important is the broader socio-cultural context for the transferability of knowledge? One reason for the distinctions between different kinds of knowledge proposed below is that they help to sort out these questions and, at the same time, refer to categories that can be useful for a discourse about the role of knowledge in connection with education and training.

Four different kinds of knowledge

Knowledge can be classified as:

Knowledge is here divided into four categories which in fact have ancient roots (Lundvall and Johnson, 1994; see also Box 1).*

- Know-what.
- Know-why.
- Know-how.
- Know-who.

– Facts or information: "know-what",

Know-what refers to knowledge about "facts". How many people live in New York, what the ingredients in pancakes are, and when the battle of Waterloo took place are examples of this kind of knowledge. Here, knowledge is close to what is normally called information – it can be broken down into bits and communicated as data.

– principles that explain: "know-why",

Know-why refers to knowledge about principles and laws of motion in nature, in the human mind and in society. This kind of knowledge has been extremely important for technological development in certain science-based areas, such as the chemical and electric/electronic industries. Access to this kind of knowledge will often make advances in technology more rapid and reduce the frequency of errors in procedures involving trial and error.

– competence and skills: "know-how"...

Know-how refers to skills – *i.e.* the ability to do something. It may be related to the skills of production workers, but it plays a key role in all important economic activities. The businessman judging the market prospects for a new product or the personnel manager selecting and training staff use their know-how. It would be

* At least two of these categories have roots that go back to Aristotle's three intellectual virtues. Know-why is similar to epistèmè and know-how to technè. But the correspondence is imperfect, since we will follow Polanyi and argue that scientific activities always involve a combination of know-how and know-why. Aristotle's third category, phronesis, which relates to the ethical dimension, will be reflected in what is said about the need for a social and ethical dimension in economic analysis and about the importance of trust in the context of learning.

Box 1. **Aristotle's knowledge taxonomy**

Knowledge has been at the centre of analytical interest from the very beginning of civilisation. Aristotle distinguished between:

- *Epistèmè*: knowledge that is universal and theoretical: "know-why."
- *Technè*: knowledge that is instrumental, context-specific and practice-related: "know-how."
- *Phronesis*: Knowledge that is normative, experience-based, context-specific and related to common sense: "practical wisdom."

misleading to characterise know-how as practical rather than theoretical. One of the most interesting and profound analyses of the role and formation of know-how is actually about scientists' need for skill formation and personal knowledge (Polanyi, 1958/1978). Even finding the solution to complex mathematical problems is based on intuition and on skills related to pattern recognition which are rooted in experience-based learning rather than on the mechanical carrying out of a series of distinct logical operations (Ziman, 1979, pp. 101-102).

… which may need in future to be shared more among firms…

Know-how is typically a kind of knowledge developed and kept within the borders of the individual firm or the single research team. As the complexity of the knowledge base increases, however, co-operation between organisations tends to develop. One of the most important reasons for industrial networks is the need for firms to be able to share and combine elements of know-how. Similar networks may be formed between research teams and laboratories.

… to produce a more composite, networked knowledge base, hence the final category: "know-who".

This is one reason why *know-who* becomes increasingly important. The general trend towards a more composite knowledge base, with new products typically combining many technologies, each of which is rooted in several different scientific disciplines, makes access to many different sources of knowledge more essential (Pavitt, 1998). Know-who involves information about who knows what and who knows what to do. But it also involves the social ability to co-operate and communicate with different kinds of people and experts.

How public or private are the four kinds of knowledge?

Technology makes it easier to disseminate some knowledge, but human networks remain crucial in accessing information…

The public or private character of these kinds of knowledge differs in terms both of degree and of form. Databases can bring together "know-what" in a more or less user-friendly form. Information technology extends enormously the information potentially at the disposal of individual agents, although the information still has to be found and what is relevant selected. The effectiveness of search machines developed in connection with the Internet is highly relevant in this context, as this helps to specify how accessible the data actually are. At CERI's knowledge seminar at Stanford University (see Foreword to this volume), Professor Hal Varian, Berkeley University, presented the most recent advances in this area, and his presentation made it clear that access to this kind of knowledge is still far from perfect. Even today, the most effective medium for obtaining pertinent facts may be through the "know-who" channel, *i.e.* contacting an outstanding expert in the field to obtain directions on where to look for a specific piece of information.

... and also in disseminating theoretical knowledge: electronic publication of results does not create instant understanding...

Scientific work aims at producing theoretical models of the *know-why* type, and some of this work is placed in the public domain. Academics have strong incentives to publish and make their results accessible. The Internet offers new possibilities for speedy electronic publishing. Open and public access is of course a misnomer, in that it often takes enormous investments in learning before the information has any meaning. Again know-who, directed towards academia, can help the amateur obtain a "translation" into something more generally comprehensible.

... so interaction between companies and academia helps build blocks of local competence – but can also make knowledge less public.

This is one strong motivation for companies' presence in academic environments and sometimes even engaging in basic research. Professor Gunnar Eliasson's concept of "competence blocks" points to a role for big companies in contributing to basic knowledge, and he argues that they tend to take over functions of "technical universities" (see Eliasson's contribution in Part II). On the other hand, close connections between academic science and the exploitation of new ideas by business in fields such as biotechnology tend to undermine the open exchange that characterises academic knowledge production.

Scientific knowledge is essential...

To gain access to scientific know why, it is necessary, under all circumstances, to invest in science. This is true for individuals and regions as well as for firms. There is much less free spillover available than assumed in standard economics (Cohen and Levinthal, 1990).

... but technical know-how can dominate...

In fields characterised by intense technological competition, technical solutions are often ahead of academic know-why. Technology can solve problems or perform functions without a clear understanding of why it works. Here, knowledge is more know-how than know-why.

... and tends not to spread easily, being difficult to formularise...

Know-how is the kind of knowledge with the most limited public access and for which mediation is the most complex. The basic problem is the difficulty of separating the competence to act from the person or organisation that acts. The outstanding expert – cook, violinist, manager – may write a book explaining how to do things, but what is done by the amateur on the basis of that explanation is, of course, less perfect than what the expert would produce. Attempts to use information technology to develop expert systems show that it is difficult and costly to transform expert skills into information that can be used by others. It has also been demonstrated that the transformation always involves changes in the content of the expert knowledge (Hatchuel and Weil, 1995). This is true of an individual's skills and competence, of professional skills and a team's competence. Eliasson (1996) has illustrated the limits of using management information systems as a substitute for management skills by pointing out the failures experienced by the otherwise successful firms.

... so access to know-how is restricted, and relies on developing staff or buying in expertise.

This means that know-how is never a completely public good and that firms get access to it only by hiring experts or merging with companies with the knowledge they want. At the visit at Hewlett-Packard's Stanford site, it was found that the company's strategy was to build in-house know-how by intensive human resource development programmes and by making it attractive for experts to remain in the company. Most other Silicon Valley companies, instead, prefer to enrich their competence by hiring experienced people in the local, extremely fluid labour market.

Similarly "know-who" relies on private assets, in the form of personal relationships. These are not tradeable...

Know who refers to a combination of information and social relationships. Telephone books which list professions and databases which list producers of certain goods and services are in the public domain and can, in principle, be accessed by anyone. In the economic sphere, however, it is extremely important to obtain quite specialised competencies and to find

Box 2. **Social capital**

Globalisation has dramatically increased the importance of what modern authors (Bourdieu, 1977; Coleman, 1988, 1990; Putnam, 1993; Fukuyama, 1995; Woolcock, 1998) have called *social capital*, which enable firmsand people to interact, exchange knowledge and conduct other business transactions quite easily. There are several competing definitions of what is at the core of the concept. The most interesting contribution from the point of view of economic development is Woolcock's. He specifies social capital along two dimensions: macro/micro and inward/outward connectivity. The constellation most supportive to economic development, according to Woolcock, is the one where local communities are both closely interconnected and open to the wider world and where the state is integrated in civil society but remains autonomous. Social capital is especially important in a learning economy since learning presumes interaction in which mutual respect and trust are crucial. If these are eroded – Russia may be an illustration – little can be learnt and existing intellectual capital may begin to disappear.

the most reliable experts, whence the importance of good personal relationships with key persons one can trust. These social and personal relationships are by definition not public. They cannot be transferred and, more specifically, they cannot be bought or sold on the market. As Arrow (1971) pointed out, "you cannot buy trust and, if you could, it would have no value whatsoever".

... but are stimulated by certain social, cultural and technological conditions.

On the other hand, the social context may support, to a greater or lesser degree, the formation of know-who knowledge while the cultural context determines the form it takes. When characterising national business systems, Whitley emphasises factors having to do with trust and the capacity to build extra-family collective loyalties (Whitley, 1996, p. 51). This is also an important aspect of the concept of social capital (Woolcock, 1998; see also Box 2). In situations where technology is characterised by rapid change or where the knowledge base is not well documented, it is necessary to meet together from time to time in order to solve problems. At the Stanford seminar, Professor Kenneth Arrow, Stanford University, emphasised the importance of face-to-face interaction to the success of the Silicon Valley.

Most knowledge is neither strictly public nor strictly private

So knowledge is rarely available freely to all...

It is clear from what precedes that very little knowledge is "perfectly public". Even information of the know-what type may be unavailable to those who are not connected to the right telecommunications or social networks. Moreover, the current state of information technology still limits access for those who are in fact connected. Scientific and other types of complex knowledge may be perfectly accessible, in principle, but for effective access the user must have invested in building absorptive capacity. Know-how is never fully transferable since how a person does things reflects that individual's personality (even organisations have a "personality" in this sense).

... but nor can it be kept fully private, even where firms try to do so.

On the other hand, little economically useful knowledge is completely private in the long run (see Box 3). Tricks of the trade are shared within the profession. Know-how can be taught and learnt in interaction between the master and the apprentice. New technological knowledge may be costly to imitate but if it is much more efficient there are several ways to obtain it. Even when the possessor of private knowledge does not want to share it with others there are ways to obtain it, such as reverse engineering which involves taking products

> Box 3. **Is it possible to define and measure knowledge as a social stock of intellectual capital?**
>
> One implication of the fact that most kinds of knowledge fall into categories in which private and public overlap is that while "the common pool of knowledge" is not empty, it is very limited. Instead, many small pools are shared by professions, regional constellations or industrial networks. This is one reason it is difficult to define and measure an economy's common knowledge stock. It reflects the fact that "the knowledge base" has very different meanings in different contexts. Talking about an economy's "knowledge base" is actually somewhat misleading. Defined in terms of a community of experts or a scientific discipline, it becomes less problematic.
>
> One problem with defining a common stock of knowledge is therefore that access to knowledge is limited. Increasing "effective supply" – by mediating knowledge and giving broader access to it – might be the most effective way to increase the "effective" stock of intellectual capital. A second problem is separating economically useful from irrelevant knowledge. Over time, some important elements of knowledge become irrelevant, while others that have appeared irrelevant take on central importance for the economy.
>
> One means used by economists to solve this problem is to look for indicators that reflect the rate of return on intellectual assets and use them to calculate the present value of intellectual capital. Human capital has been estimated in this way. Such calculations involve making a number of very broad simplifying assumptions, the most important of which is that the specific asset can be separated from other assets in terms of its contribution to productivity.
>
> A more general methodological approach is to focus on processes and flows rather than on states and stocks. This is the choice made in much of the literature on indicators based on R&D statistics, innovation surveys, etc.

apart to find out how to produce them. If necessary, private agents will engage in intelligence activities aimed at getting competitors' secrets.

Classical economics unrealistically assumes universal access to information and know-how…

Different parts of economic theory handle this mixed situation differently. Underlying much of the neo-classical theory of production and economic growth is the simplifying assumption that there is a global bank of blueprints from which anybody can get a copy to be used for starting up production. This ignores the fact that most accessible knowledge can only be used by skilled agents and that skills differ and are not easily transformed into blueprints.

… while theories focusing on unique competencies of firms are in the opposite direction.

The competence of the firm determines the directions in which it expands its activities (Penrose, 1958). The specificity of the knowledge base determines the pattern of economic growth. Actually, however, this model presupposes a dynamic perspective characterised by continuous creation of new competencies within the firm. Otherwise, imitation and innovations in competing firms would erode the firm's competencies.

On tacitness and codification of knowledge

Transferability of knowledge depends in particular on the extent to which it is tacit…

There is currently a lively debate among economists about the role of tacitness in knowledge. The reason for the interest is, of course, that tacitness relates to the transferability and to the public character of knowledge. It has been assumed that the more knowledge is tacit, the more difficult it is to share it between people, firms and regions. Specifically, markets might fail and other mediation mechanisms would have to be considered.

Tacit knowledge is knowledge that has not been documented and made explicit by the one who uses and controls it (see also Box 4). As later chapters

Box 4. **On the location of knowledge**

In theories of learning based in psychology, the focus is on individual learning; it is in fact very natural to think about knowledge as residing in individuals (Kolb, 1984). In this perspective, the competence of organisations would reflect the sum of knowledge carried by individuals. Increasingly, however, economists and experts in management science have challenged this view. In his Richard T. Ely lecture, Kenneth Arrow (1994) pointed to the limitations of methodological individualism for understanding the production of knowledge. Regional economists going back to Marshall's work on industrial districts (1919) have pointed to regional networks as locations for specialised knowledge (Maskell and Malmberg, 1999). Theories of the firm increasingly regard the competitiveness of companies as reflecting specific competencies (Teece *et al.*, 1992). Senge (1990) emphasises team learning and team skills rather than individual skills and individual learning as the key to competitiveness.

Common to these perspectives is the view that know-how knowledge is partially embedded in organisations, structures and institutions. This does not rule out the possibility that an organisation's competence may be dramatically weakened by the departure of key persons; nonetheless, a layer of knowledge (shared codes of communication, shared routines, shared methods for problem solving and searching) would normally remain.

will show, there is much tacitness in teachers' know-how. Teachers often have their own ideas about how to teach, and they seldom write them down in a form that is accessible to others.

... sometimes, but not always, because it is tacit by nature...

The fact that a certain piece of knowledge is tacit does not rule out the possibility of making it explicit if incentives to do so are strong enough. To make this clear, it is necessary to distinguish between tacit knowledge that can be made explicit (tacit for lack of incentives) and knowledge that cannot be made explicit (tacit by nature) (Cowan *et al.*, 1998).

... which is most frequently the case with know-how rather than know-what or know-why.

Skills embodied in persons and competencies embodied in organisations can only be documented to a certain degree. There are "natural" limits to how far it is possible to make "know-how" explicit; only approximations are possible. This is less true for knowledge about the state of the world. Know-what can be entered into databases and know-why can be made explicit in theorems. This is why outstanding experts whose activities are based on their unique know-how and firms whose activities are based on unique competencies and permanent innovation may earn extra rents for long periods.

Knowledge is more easily shared if it is codified; educators tend not to do so, but to rely on tacit know-how...

An important issue in this context is how much effort should be made to "codify" knowledge. Knowledge written down in a code can be accessed only by those with access to that code. Two parties can share the knowledge or one party can sell the knowledge to another. Codified knowledge is potentially shared knowledge while non-codified knowledge remains individual until it is learnt in direct interaction with the possessor. Later chapters will argue that one weakness of the education sector is the fact that its knowledge base is dominated by non-codified but potentially codifiable knowledge, and that this is one reason why systematic progress towards more efficient practices is difficult. Economists have used education as a typical example of a production process characterised by tacit techniques (Murnane and Nelson, 1984).

... but the impact of codification depends on whether codes are made explicit and hence widely useable.

The debate on codification has been complicated by the fact that two different kinds of codes have been alluded to. Some are explicit and available in the form of textbooks, manuals, formulas and organisational diagrams. Others have developed spontaneously as a means of communication within or between organisations (Arrow, 1974). The latter are implicit and no individual in the organisation may be able to give a full description. The issue of the extent to which such implicit codes can be transformed into explicit ones is an important one. It is well-known that organisational diagrams and management information systems lose some of the complexity and richness that characterise social systems. If these codes could be made explicit, they could be made available to external parties, and mediation of knowledge would become less difficult. Another reason for making implicit codes explicit might be the fact that, in some instances, this would make it easier to formulate and realise strategies of change. This may be true for schools, as the implicitness of codes may be one factor that stands in the way of knowing exactly how things are done and why they are done in a specific way.

These dimensions create different knowledge bases by sector…

What has just been considered as important attributes of knowledge (public/private; codified/tacit) suggests that there are marked differences among the various sectors with regard to their knowledge base. The diversity is so great that it may be useful to reduce it. Two parameters can be considered (the sectoral matrix presented below is fully developed by Professor Dominique Foray, see Part II).

… according first to whether the "centre of gravity" of the knowledge base lies in scientific/codified or in pratical knowledge…

The first deals with the "centre of gravity" of the knowledge base. In some sectors, the direct usefulness of R&D and the importance of codified knowledge appear to be the key determinants of the dynamics of the knowledge base. NSBiotechnology and the pharmaceutical industry share these features. In other sectors, R&D is less directly useful and codified knowledge is a small part of the knowledge base. The absence of codification makes horizontal diffusion of the best practical knowledge very difficult. Education is a case in point. Here, formal R&D is of secondary importance; experimentation at the school level and dissemination of new practical knowledge appear as the key features.

These differences are obviously related to the *centre of gravity* of the knowledge base. They indicate that the relative weight of scientific and practical elements in the knowledge base is an essential parameter, one that creates fundamental differences.

… and secondly to whether the sector is subject to market pressures, which create powerful incentives for innovation and knowledge absorption.

A second fundamental difference involves participation in the market. When a sector fully participates in the market, the functioning of the knowledge base is significantly influenced by the fact that innovation is a precondition for a business's survival; more specifically, the knowledge base's driving force is either the generation of rents from innovation or the dissipation of rents generated by the innovations of rival firms. This gives extraordinary power to the mechanisms developed for absorbing knowledge and for disseminating (whether deliberately or not) best practices and know-how. In sectors that are not fully part of the market, such as education and health, the dissemination of knowledge is less automatic, and administrative measures and other incentives aimed at disseminating knowledge will fail to have as much impact as competitive markets. Thus, involuntary spillovers and horizontal knowledge flows are considerably more significant in competitive sectors.

These two major differences are presented in the matrix below, which provides some guidelines for the evaluation and measurement of the knowledge base.

	Competitive environment	Non-competitive environment
Knowledge is poorly articulated (tacit)	Consulting activity	Education (teacher)
Knowledge is highly codified	Biotechnology	Higher education Library management

An economic perspective on the production, mediation and use of knowledge

The project focuses on sectoral differences in the production, mediation and use of knowledge; its ultimate aim is better understanding of the challenges for schools in the learning economy. This section uses the concepts developed above to specify an economic approach to the production, mediation and use of knowledge.

The above concepts can be applied as follows.

What is produced when firms produce knowledge?

Most authors using the concept of knowledge creation and knowledge production refer to technological knowledge and to technical innovation as the output of the process (Antonelli, 1999; Nonaka and Takeuchi, 1995). In the new growth theory, the output of the R&D sector is viewed as a blueprint for a more efficient new production process, possible to protect by property right instruments such as patents or, alternatively, as a new semi manufactured good that, for some reason, cannot easily be copied by competitors (Verspagen, 1992, pp. 29-30).

Knowledge can be regarded as an economic output, in the form of a production blueprint…

A striking characteristic of knowledge production resulting in innovation is the fact that knowledge, in terms of skills and competencies, is the most important input. In this sense, it recalls a "corn economy", in which corn produces corn. But it differs from such an economy in one important respect. While the corn used to produce corn disappears in the process, skills and competencies improve with use. Important aspects of knowledge are not scarce in the traditional sense: the more skills and competencies are used, the more they develop. This points to knowledge production as a process of joint production, in which innovation is one kind of output and the learning and skill enhancement that takes place in the process is another.

… but knowledge is also an input, required to produce new blueprints; unlike physical inputs, it expends with use rather than being "used up".

Innovation as the outcome of knowledge production

There are two reasons for regarding innovation as an interesting outcome of knowledge production. One is that innovation represents – by definition – something new and therefore adds to existing knowledge. The second is that innovation is – again by definition – knowledge that is in demand (see Box 5). It is defined as an invention that has been introduced in the market and it thus represents knowledge that has proven its relevance for the market economy.

Innovation is a key outcome, because it adds to knowledge and embodies its economic value…

On the other hand, it is important to note that innovation, as Schumpeter emphasised, is part of a process of "creative destruction". An innovation may open up new markets and create the basis for new firms and jobs, but it will, at the same time, close down some old markets and some firms and jobs will disappear. This has a parallel in the impact on the stock of knowledge used in the market economy. Moral depreciation of intellectual capital is the other side of innovation. For instance, the know how necessary to produce mechanical office equipment and the competencies of firms engaged in their production became obsolete when semi-conductors and computers were introduced.

… but also entails destruction of obsolete firms, jobs and knowledge.

Innovation is often thought of mainly as technical innovation in the form of new products and new processes. It may be wise not to broaden the concept too much. In terms of the impact on economic performance, however, developing and introducing new organisational and institutional ideas may be at least as important. The effect of the information technology revolution on productivity has been much less dramatic than expected (the so-called

Changes in organisations can be as important forms of innovation as new products and processes.

Box 5. **Adam Smith on knowledge production as the outcome of learning and searching**

Adam Smith was aware that knowledge production/innovation could be rooted either in experience-based learning or in specialised knowledge production.

"Many of the machines used in manufacturing industries where tasks are most subdivided, were originally the inventions of common workmen, each of whom performed some very simple operation and naturally sought ways to perform it more easily.

"All the improvements in machinery, however, have by no means been the inventions of those who had occasion to use the machines. Many (...) have been made by the makers of the machines, when to make them became the business of a peculiar trade: and some by (...) those who are called philosophers, or men of speculation, whose trade is not to do anything but to observe everything: and who, upon that account are often capable of combining together the powers of the most distant and dissimilar objects (...). Like every other employment (...) it is subdivided into a number of different branches, each of which affords occupation to a peculiar tribe or class of philosophers; and this subdivision of employment in philosophy, as well as in every other business, improves dexterity and saves time (Smith, 1776, p. 8)."

"Solow paradox"). A major reason is that changes in organisational and institutional frameworks have not kept pace with technological changes, thereby creating mismatches which have affected productivity growth negatively (David, 1991).

The nature and results of innovation differ among sectors according to the place of suppliers, customers, process technology and scientific advance...

This report focuses on sectoral differences in knowledge production, so that differences in the ways that private sector technical innovations are developed are relevant to the outcome of the innovation, the mode of innovation, and the outcome of the innovation process. The taxonomy developed by Keith Pavitt (1984) represents an important effort to capture these differences systematically. By analysing 2 000 important technical innovations in the United Kingdom, Pavitt defined four categories of firms and sectors. First, there are *supply-dominated* sectors (*e.g.* clothing, furniture), in which firms develop few important innovations on their own, but obtain some from other firms. Second, there are *scale-intensive* sectors (*e.g.* food, cement), which focus their innovation activities on developing more efficient process technology. Third, there are *specialised suppliers* (*e.g.* engineering, software, instruments), and these carry out frequent product innovations, often in collaboration with customers. Finally, there are *science-based producers* (*e.g.* chemical industry, biotechnology, electronics) which develop new products as well as processes in close collaboration with universities.

... but only lately has it been recognised that scientific breakthrough leading to invention is not the primary route to innovation: although science often plays a part...

For a long time, knowledge production/innovation processes were considered largely as the province of the fourth category, and still there is a bias in this direction, often in combination with a linear view which assumes that new scientific results are the first step in the process, technological invention the second step, and the introduction of innovations as new processes or products the third. There is now a very rich body of empirical and historical work which shows that this is the exception rather than the rule (Rothwell, 1977; von Hippel, 1988; Lundvall, 1988). Of all scientific advances, very few are immediately transformed into innovations and, vice versa, innovations very seldom reflect recent scientific breakthroughs. However, knowledge production/innovation processes are facilitated by science in various ways, although generally it is old rather than new scientific results that support the innovation process. Kline and

Rosenberg (1986) have reviewed the complex interaction between science and technology throughout the innovation process.

… innovation is a complex rather than a linear process, with interactions among many actors creating innovation systems within regions or nations.

The recent models of innovation emphasise that knowledge production/ innovation is an interactive process in which firms interact with customers, suppliers and knowledge institutions. Empirical analysis shows that firms seldom innovate alone. This is also the background for developing a systemic approach to knowledge production. Innovations systems are constituted by actors involved in innovation and their interrelationships. The actors are firms, technological institutes, universities, training systems and venture capital. Together they constitute the context for knowledge production and innovation. The specific constellations differ across sectors, regions and nations. They are typically specialised in terms of their knowledge base, and the specific mode of innovation will reflect institutional differences. This is the background for the growing literature on innovation systems (Freeman, 1987; Lundvall, 1992; Nelson, 1993; Edquist, 1997) and technological systems (Carlsson and Jacobsson, 1997). Innovation systems may be defined as regional or national, as well as sector- or technology-specific. The common idea is that the specificities of knowledge production will reflect a combination of technological specialisation and institutional structure. In national systems, the education and training system is among the most important for explaining national patterns and modes of innovation.

Knowledge can flow less freely where it is not made explicit; efforts to make it more so in the case of business services may offer lessons to the education sector.

Another distinction between sectors that plays an important role in analysing education, as compared to other sectors, is the extent to which the knowledge base is well-structured and explicit. In the private sector as well, it is sometimes difficult to make explicit the knowledge base of some activities. It is true in particular for the most rapidly growing sector in OECD economies, *i.e.* knowledge-intensive business services, and efforts are currently being made to overcome this situation. The success or failure of these efforts may give ideas for developing a strategy for the reform of knowledge production in education.

Competence as the outcome of knowledge production

Where innovation is interactive, it can build competence among all involved…

The change from a linear to an interactive view of innovation and knowledge production has also been a way to connect innovation and the further development of competence. As now understood, the innovation process may be described as a process of *interactive learning* in which those involved increase their competence while engaging in the innovation process.

… as they learn by engaging in production, by using complex systems, by producer-user interaction or by confronting new production problems…

In economics, there have been various approaches to competence-building and learning. One important contribution is Arrow's analysis of "learning by doing" (1962*a*), in which he demonstrated that the efficiency of a production unit engaged in producing complex systems (aeroplane frames) grew with the number of units already produced and argued that this reflected experience-based learning. Later, Rosenberg (1982) introduced "learning by using" to explain why efficiency in using complex systems increased over time (the users were airline companies introducing new models). The concept of "learning by interacting" points to how interaction between producers and users in innovation enhances the competence of both (Lundvall, 1988). A more recent analysis of learning by doing focuses on how confronting new problems in the production process triggers searching and learning, which imply interaction between several parties as they seek solutions (von Hippel and Tyre, 1995).

… but beyond these spin-off benefits of economic processes, organisations may structure themselves intentionally to enhance learning…

In most of the contributions mentioned above, learning is regarded as the unintended outcome of processes with a different aim than learning and increasing competence. Learning can be a side-effect of processes of production, use, marketing, or innovation. An interesting new development, which tends to make learning more instrumental, is the growing attention given to "learning organisations" (Senge, 1990). The basic idea is that the way an organisation is structured and the routines followed in it will have a major effect on the rate of learning that takes place. The appropriate institutional structures may improve knowledge production in terms of competence building based on daily activities.

… by creating flatter hierarchies within firms and refining relationships with suppliers, customers and competitors…

The move towards learning organisations is reflected in changes both in the firm's internal organisation and in inter-firm relationships. Within firms, the accelerating rate of change makes multi-level hierarchies and strict borders between functions inefficient. It makes decentralisation of responsibility to lower-level employees and formation of multi-functional teams a necessity. This is reflected in the increasing demand for workers willing to learn and, at the same time, skilful, flexible, co-operative and willing to shoulder responsibility. Inter-firm relationships with suppliers, customers and competitors become more selective and more intense. "Know-who" becomes increasingly important in an economy that combines a complex knowledge base and a highly developed, rapidly changing specialisation.

… as well as making learning more explicit and conscious among employees; this makes work-based learning more relevant to educationists…

Apart from these organisational changes, there is a growing emphasis on making employees and teams of employees more aware of the fact that they are engaged in learning. It has been suggested that second-loop learning, *i.e.* in which the crucial element is reflecting on what has been learnt and on how to design the learning process, is more efficient than simply relying on the impact of experience (Argyris and Schön, 1978). These new developments in the private sector are also interesting in that they signal a certain convergence of concerns between education specialists and management. To build schools as learning organisations may be one of the major challenges for the future.

… but while more learning appears to take place in innovative sectors, it is hard to measure competence building other than through its application…

In empirical terms, it is more difficult to capture competence building through learning than innovation. Competence is revealed in practice but in no other way. This may become a problem as experience-based learning and competence become increasingly important for the competitiveness of workers, firms and regions. Tomlinson (1999) has made an interesting and original attempt to map sectoral differences in competence building through experience. Using UK labour market survey data, he shows that learning is more intensive and extensive in the top than in the bottom of organisations. His data also indicate that learning is more important in sectors characterised by frequent innovation. When it comes to the development of indicators, however, this is the most difficult but also the most important area.

… and economists have put much more effort into understanding innovation than learning – on which other disciplines have more to offer.

These measurement problems reflect the general state of economic analysis in this field. While economists have made a very substantial contribution to the economics of innovation, their contribution to understanding competence building is much more modest. With scholars such as Christopher Freeman, Richard R. Nelson and Nathan Rosenberg as entrepreneurs and spiritual leaders, there has been a massive effort to understand the process of innovation in relation to economic theory (Dosi *et al.*, 1988) and in an historical and empirical perspective, including the development of statistical indicators. There is no parallel for knowledge production as learning and competence building. On this aspect of knowledge production, non-economists and education specialists have more to offer to economists in terms of systematic insights than *vice versa* (see, for instance, Kolb, 1984).

Production of knowledge as a separate activity or as a by-product of regular routine activities: a differentiation which is becoming blurred

Two strands of thinking can be distinguished:

It is useful to separate two different perspectives on the process of knowledge production which are not mutually exclusive but which can be found, in more or less pure form, in the literature on innovation systems and the information society. They are also reflected in attempts to measure the relative importance of knowledge in the economy and in theoretical models such as models of economic growth.

First, the idea of a "knowledge sector" beyond production; second, the incorporation of knowledge processes into productive activity…

On the one hand, one might look for *a separate sector* in charge of producing new knowledge or handling and distributing information. Such a sector could involve universities, technical institutes and government S&T policies, as well as R&D functions in firms. Here, the production of knowledge would take place as a deliberate activity, outside the realm of production. On the other hand, one might regard the creation and diffusion of knowledge as rooted in and emanating from routine activities in economic life, such as learning by doing, by using and by interacting. Here, the production of knowledge would take place as a by-product of production, through learning by doing or learning by using.

… but the distinction is blurred by experimentation in productive processes, which becomes more important in knowledge economies…

The distinction is between deliberate and non deliberate forms of knowledge production, "off-line" and "on-line" learning activities. Some recent trends, however, make it less relevant. This is particularly true for the emergence of a form of learning qualified as "experimental". This form of learning, which takes place "on line" (that is to say, during the process of producing the good or providing the service) consists in experimenting during the production process. By doing so, one creates new options and variety. This form of learning is based on a strategy whereby experimentation allows for collecting data, on the basis of which the best strategy for future activities is chosen. For example, a professor can undertake pedagogical experiments; the craftsman can seek new solutions to a problem even during the fabrication process. The possibility of moving to this type of learning in many activities represents an important transition in the historical emergence of the knowledge-based economy. In effect, as long as an activity remains fundamentally based on learning processes that are routine adaptation procedures and leave no room for programming experiments during economic activity, there remains a strong dichotomy between those who deliberately produce knowledge and those who use and exploit it. When an activity moves to higher forms of learning and where the individual can programme experiments and obtain results, the production of knowledge becomes much more collectively distributed.

… in which disengaged research needs to be better linked to learning within production, partly through better recognition of the latter.

Thus, new forms of learning are emerging which are neither pure "off-line" experiments nor pure "on-line" by-products of learning. With the emergence of experimental learning, the feedback and reciprocal links that tie "on-line" learning process and in-house R&D together – and whereby a potentially creative activity effectively contributes to the production of knowledge – become crucial. The main issue here is determining the extent to which the knowledge produced "by doing" is valued. However, production activities are rarely considered by firm management as activities that produce knowledge, although different national systems differ markedly in this respect. The establishment of feedback loops therefore requires very specific conditions of organisation, which depend on effective recognition, identification and valorisation of the knowledge produced through the learning process.

Mediation of knowledge

As well as the production of knowledge, its mediation and use are important…

While the production of knowledge is important for the overall dynamics of the global economy in the long run, there is also great economic potential in broadening the use of knowledge in the economy. This is reflected in public efforts to increase the diffusion of innovations as well as in training and education aimed at the formation of skills and competencies. How can different aspects of knowledge be mediated? The natural starting point for an economic analysis is to see under what conditions the market can mediate knowledge.

… but some knowledge is hard to transmit, or "sticky"…

Some of the difficulties in mediating knowledge through the market have already been indicated. Tacit knowledge in the form of know-how or an implicit code or competence cannot be separated from the person or organisation containing it. This is what von Hippel (1994) call "sticky data". In this case, mediation may take the form of the purchase by the customer of the services of the person or the firm rather than the competence itself.

… and thus hard to verify to clients, although testimonials can help.

Carriers of such knowledge may have a problem demonstrating the quality of their competence to potential buyers and buyers may have a problem locating the best offers in terms of quality. References from key customers which can be shown as evidence to potential customers is one strategy used by firms operating in this kind of market. (The situation of schools may be similar, and it may be possible to learn from private knowledge mediation in this respect.)

Mediation is growing in importance, and with it the number of professional knowledge entrepreneurs…

This form of mediation and the problems it involves tend to take on growing economic importance. The increasing specialisation in the production of knowledge makes mediation more crucial for the system as a whole. This is reflected in the fact that knowledge-intensive business services, a sector directly engaged in the production and sale of knowledge, are now the most rapidly growing sector in most OECD countries.

… but more direct transmission can also occur between individuals, or by buying in knowledge holders.

A second way to mediate this kind of knowledge is to engage in a process of interactive learning with the carrier of the knowledge. This may be a conscious choice, for example when an apprentice enters into a contract with a master, or it may be a side-effect of co-operation between people and organisations to solve shared problems. A third way to obtain this kind of knowledge is to hire experts as employees or take over the organisation controlling the knowledge.

Markets in knowledge mediation can have problems in determining prices and restricting replication…

Even when knowledge is explicit and can be separated from its carrier there are problems with using the market as a mediator, which Kenneth Arrow, in particular, has worked to define. One is determining the value of the information for the user before the transaction takes place; a user wants to know something in advance about the knowledge, and the seller does not want to give information away for free. Another is the difficulty for the seller to restrict the use of the information once it has been sold and, *vice-versa*, the difficulty for the buyer to restrict its further distribution by the seller.

… but are nevertheless growing, helped by legal frameworks, reputation and trust.

Despite these difficulties, a large and growing amount of knowledge is the object of transactions in something that looks like a market (there is a buyer, a seller and a price). One reason why markets work is that formal and informal institutions – including legal protection in terms of patents, licenses and copyright – help make the market work. Reputation lowers the risk for entering into contractual relationships. Another reason is that many markets for knowledge transactions are organised markets. Long-term relationships with elements of experience-based trust often play a major role in knowledge markets (Lundvall, 1988).

Knowledge can also be mediated by scientific instruments and computers, often with human backup...

So far, the discussion has been limited to the mediation of what economists call disembodied knowledge. Substantial flows of knowledge are also built into products. Scientific instruments and computers embody a great deal of knowledge, and users with sufficient competence can perform very advanced operations with this kind of equipment. Mediation of knowledge via embodied technology is sometimes combined with a transfer of disembodied knowledge. For example, suppliers of complex process equipment may offer training to the personnel of the customer organisation.

... and through informal exchange.

Finally, knowledge can be mediated in several other informal ways. One way to overcome market limitations is for professionals belonging to separate and sometimes even competing organisations to exchange pieces of knowledge on a barter basis (Carter, 1989).

Codification knowledge and the mediation of knowledge

When knowledge is codified to make it more explicit, the codes need to be made accessible.

The process of codification of knowledge plays an ambivalent role in the mediation process. On the one hand, the production and use of highly specialised codes or codes using technical or local jargon would create an obstacle to appropriation of the field by lay people and potential users of the knowledge. On the other hand, a lack of codification would also create an obstacle as users would not have access to sufficiently explicit knowledge. This ambivalence indicates the importance of designing and implementing metacodes or semicodes as mechanisms for developing compromises between the need to make knowledge more explicit and the need to avoid excessive technicalities and local jargons.

Conclusions on the contribution of economic analysis to the understanding of knowledge

Knowledge is at the centre of economics, but economists have made varying assumptions about how much is known...

It may be argued that, in a sense, all economic theory is about information and knowledge. Problems of co-ordination have been at the core of economic theory since Adam Smith. Individual agents make choices independently on the basis of information offered by the market. Important differences between economic models and theories reflect differences in the assumptions made about what agents know and about the degree to which they learn anything from what they do. This separates neo-classical economics from Austrian economics; the former takes fully informed agents as the reference, whereas the latter emphasises ignorance as the starting point for learning (von Hayek). It also separates those who assume hyper-rationality and rationality from those who assume limited rationality (Herbert A. Simon).

... however, modern ones have put renewed stress on the process of acquiring it...

Modern economics is more than ever aware of the importance of knowledge and learning. New growth theory and new trade theory assume a strong link between the increase in the knowledge base and the rate of productivity growth. Austrian economists treat learning as a fundamental process in the analysis of market transactions. The last decades have witnessed an explosive growth in institutional economics and the economics of innovation. In these new fields, knowledge and learning play a pivotal role in economic development. New theories of the firm focus on building capabilities and competencies. The management literature has made the concept of "learning organisations" central for theoretical developments and for practitioners.

... yet still take a narrow view of learning, with sometimes contradictory assumptions about its influence...

However, in almost all of these contributions, the understanding of knowledge and learning remains narrow. In theories that form the core of standard economics, it is assumed that rational agents make choices on the basis of a given amount of information. The only kind of learning allowed for is agents' access to new bodies of information. The most recent developments within standard economics are contradictory and ambivalent in this respect. On the one hand, new growth theory and new trade theory focus on the importance of investments in education and research. On the other hand, some of the most fashionable developments in macroeconomics assume rational expectations and thus operate with even more extreme assumptions, leaving no room for learning by agents.

... although efforts to look more empirically at influences on innovation have made progress...

Recent developments outside standard economics have been less constrained. Research on the economics of institutional and technical change has resulted in many new insights. Institutional economics, evolutionary economics, socio-economic research and the economics of innovation have typically been developed in close interaction with historical and empirical research programmes. This is why we now know much more than before about how innovation takes place in different parts of the economy.

... but less so economic research on individual and organisational learning: here, other disciplines need to be brought in...

When it comes to the other aspect of knowledge production, *i.e.* competence building and learning, research is only now beginning to raise fundamental questions about who learns what and how learning takes place in the context of economic development. In this area, economists have a lot to learn from other disciplines and not least from education specialists who have developed a much more systematic and empirically based understanding of learning (Kolb, 1984). This reflects the fact that when economists begin to focus on learning, they face issues for which their traditional toolbox is insufficient. Scholars in philosophy, psychology, education, anthropology and other disciplines have illuminated different aspects of these issues. The increasing division of labour in the production of knowledge described by Adam Smith (see Box 5) has had as a negative consequence the lack of a more holistic understanding of the complex process of knowledge creation and learning.

... and inspiration may be drawn from breakthroughs made in the 1960s in understanding the contribution of science and technology.

When intensifying the effort to better understand knowledge creation and learning, some inspiration may be drawn from the OECD's experience in an area where it played a key role in initiating a new field of research. More than 30 years ago, the interest of policy makers in the role of science and technology in relation to social and economic development was growing. The area was covered very little in academic research. The OECD, together with key people like Christopher Freeman and Richard R. Nelson, played an important role in changing this situation. In part as a result of these efforts, research on science policy, and later on technology and innovation policy, became legitimate academic activities in universities. In parallel, the OECD co-ordinated efforts to develop a set of internationally comparable indicators in the fields first of R&D and later of innovation activities.

Towards the learning economy and the role of education

The shift to a learning economy...

Many indicators show that there has been a shift in economic development in the direction of a more important role for knowledge production and learning. This section looks at some of these changes and the issues they raise for the knowledge base of the education system.

Moses Abramowitz and Paul David (1996) have demonstrated that this century has been characterised by increasing knowledge intensity in the production system. The OECD's structural analysis of industrial development supports their conclusion. It has been shown that the sectors that use knowledge inputs such as R&D and skilled labour most intensively grow most rapidly. At the same time, the skill profile is on an upward trend in almost all sectors. In most OECD countries, in terms of employment and value added, the most rapidly growing sector is knowledge-intensive business services (OECD, 1998*a*, pp. 48-55).

... has entailed greater use of knowledge inputs and a rising skill profile...

These observations have led more and more analysts to characterise the new economy as "knowledge-based", and there is in fact little doubt about a relative shift in the demand for labour towards more skilled workers (OECD, 1994). However, if the knowledge intensity of the economy were to increase permanently, the destructive aspects of innovation and change might take on greater importance. In an alternative interpretation of the change in the composition of the labour force, Anne P. Carter (1994) pointed out that the main function of most non-production workers is to introduce or cope with change. The rising proportion of non-production workers may thus be taken as the expression both of the growing cost of change and of an acceleration in the rate of change.

... but this may bring the economy into a permanent state of flux, with important costs...

Box 6. **Defining learning in the context of the learning economy**

In the present context, learning is defined as a process, the core of which is the acquisition of competence and skills that allow the learning individual to be more successful in reaching individual goals or those of his/her organisation. It will also involve a change in context of meaning and purpose for the individual and affect his/her existing knowledge. This corresponds closely to what is commonly meant by learning and to what experts on learning, who are not economists, understand by the concept (Kolb, 1984). It is also the kind of learning most crucial to economic success. It differs from some definitions of learning in standard economic theory, where it is synonymous either with "information acquisition" or treated as a black box phenomenon assumed to be reflected in productivity growth.

An acceleration in the rate of change implies that knowledge and skills are exposed more rapidly to moral depreciation. Therefore, the increase in the stock of knowledge may be less dramatic than it appears. An alternative hypothesis is that we are moving into a "learning economy", where the success of individuals, firms, regions and countries will reflect, more than anything else, their ability to learn (see Box 6). The speeding up of change reflects the rapid diffusion of information technology, the widening of the global marketplace, with the inclusion of new strong competitors, and deregulation of and less stability in markets (Drucker, 1993; Lundvall and Johnson, 1994; and the contribution by Lundvall in Part II).

... and the stock of knowledge growing less rapidly than its turnover might imply; an alternative emphasis is on the emergence of learning as the key to success...

These new developments are reflected in the new focus on learning organisations. They may also be a major reason for the relative weakening of the position of unskilled workers.

... with costs for the unskilled.

Social capital in the learning economy

The preceding sections have emphasised difficulties in mediating competence and skills. While the transfer of information may appear to be a techno-economic process (limited by progress in information technology), the learning of more or less tacit skills is always a social process which involves the whole

Learning is a social not just a technical process.

personality of the individual student and usually interaction with others as well. The relationships among people involved in interactive learning are crucial for what is learnt. Mutual respect and trust are important prerequisites for this kind of learning.

... but more aggregate learning, if unevenly distributed, could undermine social capital – so social not just technical innovation is needed.

On the other hand, social capital (see Box 2) may be either supported or undermined by what occurs in the learning economy. Learning and knowledge creation may for instance be threatened if social cohesion is undermined (for sustainable reproduction of intellectual capital, there is a need to secure the reproduction of social capital). This is important since there are forces in the learning economy that undermine social cohesion. The speed-up in the rate of change and increased requirements for rapid learning tend to exclude slow learners. If not consciously countered, the result will be growing social polarisation. This may be the major reason for the relative weakening of the position of unskilled workers found in the OECD *Jobs Study* (OECD, 1994). A major policy issue is therefore to know that social innovations, including innovations in education, are necessary in order to counter these tendencies.

The role of schools in the learning economy

The above poses challenges for education, particularly in developing lifelong learning for all, and collaborating with other learning organisations...

What are the new challenges for education posed by the shift to a learning economy? Some are obvious and already generally recognised by policy makers. First, students should be prepared for a professional life characterised by rapid change, where learning by doing and learning in interaction with others is crucial for economic success and social cohesion. Second, those who may be slow learners must receive a better foundation for taking part in social and economic activities. Third, adult training as part of life-long learning is a key element of the learning economy. Fourth, the ethical dimension and the contribution to the formation of social capital are increasingly important. Fifth, the rapid growth of knowledge production and knowledge mediation in the private sector may call for a new division of labour and collaboration between schools and other places of learning.

... taking account of the diversity of learning processes across sectors...

When considering the impact of these changes on schools, it is important to take into account the context specificity of learning and knowledge creation. The knowledge base as well as the modes of learning differ across individuals, firms, sectors and regions. This implies that the skills needed and the most adequate learning styles (see Kolb, 1984) will vary with professions and industries. This implies a need for diversity in general education and an awareness of specific requirements for specialised training.

... and across countries and cultures – although cross-national lessons can add value.

Another aspect of context specificity has to do with the level of the education system. Historically, the establishment of a national education system was a major element in constructing the modern nation state. Today, how the characteristics of these national systems affect knowledge creation and learning may be the most important foundation for differences in national innovation systems. Education is strongly rooted in historically established cultural traditions. Views on the role of education differ across countries and reflect deeply ingrained norms and conventions. The national socio-economic context differs as well and gives the education and the wider learning system different functions and objectives. There is a great potential for using cross-country comparisons to learn how schools interact with firms and other knowledge institutions in building tacit and explicit knowledge.

The problem for education

These new challenges call for new forms of organisation for schools as well as new content and new teaching methods. Change presupposes an increased awareness of how knowledge is produced, mediated and used in schools. Educators are good at using and transferring knowledge, but somewhat less accustomed to reflecting on how they use and transfer it. If their knowledge improves in this respect, would education be more "productive" in terms of achieving stated goals with a given level of resources? Productivity is not a familiar idea in education, and there is no tradition, as there is in fields such as medicine, for making new techniques available to make pedagogy significantly more effective.

For educators to use and transfer knowledge more effectively, they need first to become more aware of how they do so…

In recent years, there has been a strong political drive towards "school improvement", based on the assumption that education is not fulfilling its potential. Educators are under pressure to improve their techniques, especially from parents, policy makers and firms who want to see an improvement in the output of education. One aspect of this is the need to raise the attainment of the lowest achievers and thus to make learning accessible to all. Another pressure, coming particularly from firms, is for an emphasis on learning-to-learn rather than diplomas. In an economy in which competition becomes increasingly based on knowledge and accelerating innovation (EIRMA, 1993), the quality of a product or service depends more and more on the competence and ability to learn of each person involved in producing it, as well as his/her ability to co-operate. This poses radical challenges to pedagogy and to the way schools define and measure their outputs.

… they are already under pressure to raise the attainment of low achievers and to make learning more relevant; this requires competence building among teachers…

To meet such new challenges, education itself needs to undergo a major process of learning and change. Yet the strongest means of transmitting knowledge about education processes remains initial teacher training. Initial training is, however, inherently conservative, since it ingrains the norms of a particular era in a teacher's behaviour. Moreover, teacher training institutions themselves often have ingrained perspectives which do not change readily as a result of new knowledge, such as educational research findings.

… and a learning process that improves on existing initial teacher training.

These considerations raise a series of issues for the production, dissemination and use of knowledge in the education sector. The first and most straightforward is the relationship between research, on the one hand, and policy and practice, on the other. Work in this area by CERI (see OECD, 1995 and 1996*b*) has already pointed to the need for closer partnerships between researchers, practitioners and intermediaries to bring scientific knowledge to the attention of decision makers at appropriate times. A second issue, also explored in recent CERI reports, is ensuring that teachers' learning is continuous and that a new professionalism accepts the need to acquire and apply knowledge as it develops (see OECD, 1998*b*; Chapter 2 in 1998*c*).

This makes it important to build closer links between research and practice in education, and to ensure that teacher learning is continuous…

Neither the transmission of scientific knowledge nor teachers' continuous learning processes, as individuals or in groups, can be adequately understood without addressing the more complex question of how knowledge is effectively developed, disseminated and applied in practice. A key ingredient of successful school improvement has been the ability of teachers to escape from the isolation of the classroom and share expertise and know-how. Increasingly, networking and the sharing of semi-formalised knowledge and understanding are becoming important in changing education and are probably more so than external research findings. In this respect, a lot can be learnt from what is happening with knowledge production in the private sector (see Chapter 3). Under

…but also to understand how knowledge about teaching is developed and applied; in particular the role of networks can be analysed with reference to other sectors…

this model, each school becomes not only a consumer but also a producer of knowledge.

... such as electronic engineering and medicine, where innovation spreads like wildfire.

Nevertheless, the role of different types of knowledge in influencing educational practices remains poorly understood. Transmission mechanisms are frequently under-developed and even *ad hoc* in character. So it is natural for educators and for CERI to ask whether lessons can be learned from other sectors. What kinds of knowledge development and transmission processes allow electronics engineers to innovate at such a rate that products are obsolete within a few years or allow constant advances in medicine to be known to millions of doctors throughout the world within a relatively short space of time? Despite differences among these sectors which must be recognised, the parallels and lessons are worth exploring.

Knowledge beyond the school gate

Cross-sector comparisons...

CERI's examination of knowledge production, mediation and use in various sectors aims to allow educators and others to learn from how things are done elsewhere.

... offer educators the chance to understand learning with wider, cross-disciplinary networks.

The discussion that follows brings the sectoral analyses together. Although it remains a preliminary overview of the processes at work, it identifies a number of ways in which micro-level understanding is important, alongside the more macro-level insights of many economists. This is significant for policy makers who wish to implement changes in education. To do so requires a qualitative understanding of knowledge production, dissemination and use. Education specialists need to become parts of wider networks in which ideas about how knowledge can be produced and applied are exchanged. If the multidisciplinary, multi-sectoral approach used by CERI in this exercise contributes to such cross-fertilisation of ideas, its primary objective will have been fulfilled.

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Chapter 2

THE PRODUCTION, MEDIATION AND USE OF KNOWLEDGE IN DIFFERENT SECTORS

Introduction

Education is in the knowledge business, since it is primarily concerned with the transmission of knowledge of the kind which fills text-books and is the object of tests and examinations. The knowledge that forms the content of the traditional curriculum is not the focus of this study, which is more concerned with the nature and development of the professional knowledge and understanding of the processes of teaching and learning and the ways in which these will develop and change in the knowledge economy, where education has an enhanced role. The new demands on education systems take different forms. Schools, colleges and universities are now expected to teach their clients more effectively and more efficiently: students spend longer in formal education but must achieve higher levels of learning in shorter times and at lower costs. Informal learning outside the school and workplace is often neglected, yet, when properly harnessed, it complements, and contributes to, formal learning. Though education serves wider social and personal goals than preparation for work, how knowledge acquired in formal contexts and on-the-job training contribute to effectiveness in the workplace needs to be better understood. Moreover, in the knowledge economy students need to learn how to learn and how to manage their own learning, which amounts to a new form of curriculum designed to support "lifelong learning". Educationists will thus have to learn how to create new knowledge about their business and how to apply it successfully in new and very uncertain conditions. The innovations required to meet these demands depend upon an improved understanding of how new knowledge is produced, mediated and applied in order to enhance the overall effectiveness of the education system.

This study looks at how education can fit into the wider knowledge business, by learning new ways of serving demand for new kinds of competency...

In the opening chapter knowledge was analysed in terms of different types. The processing of knowledge can also be analysed under different headings: how it is created or produced; how it is mediated or transported from its source to other actors or locations; and how it is used or applied to achieve some practical goal. These processes are complex and not well understood. A comparative study of the production, mediation and use of knowledge in different sectors was therefore undertaken to achieve two purposes: first, to illuminate the general nature of these processes in modern economies; and secondly, to clarify how knowledge has hitherto been produced, mediated and used in the education sector *and to suggest how these might need to be changed in an education system adapted to meeting the demands of knowledge economies and learning societies.* Education systems are increasingly linked to a range of occupational sectors that are coping with problems of knowledge and learning. From the study of how these other sectors handle such problems, educationists may gain insights into the limitations of their present knowledge about

... and examining how in general terms and in specific sectors knowledge is produced, mediated and used, from which educationists may gain insights.

the process of education, about what new knowledge is likely to be needed, about how knowledge is successfully managed, and about the new partnerships, strategic alliances, and networks that will probably be required in societies committed to lifelong learning.

Of the sectors chosen:

The three selected sectors are engineering, health and information and communication technology (ICT):

– engineering illustrates technology transfer…

– Engineering offers a "classical" model of technology transfer, how scientific knowledge is generated and then applied in industry to manufacture new goods. Does this model really work in engineering? Can it be used to understand equivalent processes in other sectors, including education?

– health, a professionalised sector under pressure…

– Health professionals, like education professionals, have been under pressure in recent times to improve their knowledge-base to enhance the quality and cost-effectiveness of their services to clients with rising expectations and understanding of modern medicine. Have teachers anything useful to learn from doctors?

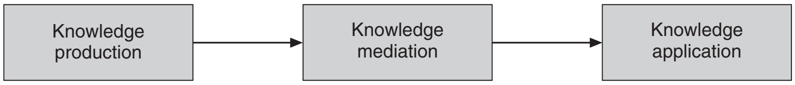
– and ICT, a rapidly innovating sector and one on which other sectors draw.

– Information and communication technologies are selected because they serve a double function. They merit investigation in their own right, for here is a field in which the production, mediation and application of knowledge must be achieved with speed and efficiency if high-tech firms are to survive commercially. Such firms should provide powerful insights into the nature of successful innovation. At the same time, most other sectors, including education, health and engineering, now draw upon ICT as a means of disseminating or mediating their own sectoral knowledge, and thereby transform some traditional means by which knowledge has been created and diffused. Do the new technologies offer lessons to medicine and education, either in suggesting a different model for the production, mediation and use of knowledge, or because they now play a new and distinctive role in almost every contemporary sector where knowledge has to be created, disseminated and applied?

Each sector is itself heterogeneous, but the analysis focuses on knowledge-intensive parts of them. It also takes account of inter-sector cultural differences.

Each of the selected sectors is highly diverse in its composition. The differences between primary and secondary education in schools, and between schools and vocational colleges and large universities, which severely limit generalisations that might be made about the changing nature of teaching and learning in learning economies, are mirrored by the internal differentiation in the fields of medicine and engineering. Medicine is differentiated into the core medical and surgical specialities, each of which has many sub-specialities, and there are obvious differences between general medical practitioners and specialists working in hospitals. Engineering similarly has many branches. In this chapter the focus is on the knowledge-intensive aspects of medicine and "high tech" engineering, and on the knowledge-intensive fields which link the two sectors, such as pharmaceuticals and biotechnology. ICT is self-evidently knowledge-intensive. The sectors also vary in the extent to which cultural factors influence how knowledge is conceptualised and used: the cultural loading is probably greatest in education and at it lowest, but still far from negligible, in high-tech industries, with medicine falling between the two. All these differences affect comparisons between the sectors and lessons that may be drawn from such comparisons.

Figure 1. **A linear model**



The model of knowledge processes within sectors is changing, and is not always based on knowledge creation followed by application in a linear fashion…

The previous chapter explored developments in conceptions of knowledge. A theme running through this chapter is the changing *models*, in both the analytic and prescriptive sense, of the production, mediation and application of these various forms of knowledge that operate in different sectors. Indeed, the very way in which the phenomena are stated implies a *linear* model: first there is the production or creation of knowledge; this is followed by its mediation (dissemination, transfer) from its source to recipients; and finally the knowledge is then used or applied (Figure 1). There have been some outstanding successes of knowledge creation and application that conform to the linear model, not least where the knowledge has been produced in a university and then successfully applied in industry. At the same time, the linear model has sometimes failed: knowledge production has not been followed by successful application.

… first because in each of seven processes such a model can fail…

As the discussion will reveal, there are two main problems with this model. First, the linear model is a complex sequence embracing at least seven complex processes, in each of which a variety of factors can cause the model to fail. The processes, and their associated problems, are:

1) *Production*

The circumstances under which individuals, groups or organisations successfully generate new knowledge and practices are still only partially understood.

2) *Validation*

Knowledge, once created, has to be shown to be valid by some criterion. This process takes different forms in different sectors. In industry there is a commercial element: if a product sells, that is a form of validation. At the same time, new knowledge may be validated by science, and there may be a pragmatic approach that some new technology "works" even though no scientific explanation is available. In the pharmaceutical industry there has been a shift from the pragmatic approach (the trial-and-error search for a drug that works on a disease) to a more scientific one (understanding the disease and then designing a drug for it). Pragmatic validation sometimes applies in medicine: exactly how anaesthetics make us unconscious is not fully understood, but this has not inhibited their constant application by anaesthesiologists. Parallel examples abound in engineering, where the technology often precedes the science, as in aircraft design (Nelson, 1993). In education, very few professional practices are grounded in science. The dominant form of validation is pragmatic: teachers do what they find will work. Here, however, the science has rarely followed successful technology.

3) *Collation*

Within an area (*e.g.* the development of a new product, a fresh teaching strategy, the successful management of a rare disease) a corpus of knowledge of what is known has to be collated and set out in a codified form. In different sectors, the obstacles to collation may vary, as may techniques for removing such obstacles.

4) *Dissemination*

There are many forms of this diffusion, *e.g.*:

– By the media (books, magazines/journals, films, etc.).

– By courses provided for professionals.

– Personal contact as the mediator.

Each of which has the potential to distort the new knowledge or obstruct its communication. The character of the new knowledge, or of the actors and organisations involved, or the process of communication, may all impede dissemination.

5) *Adoption*

There has to be a reason or incentive why a profession or organisation should be willing to adopt disseminated knowledge or practices, since more often than not adoption means giving up an existing practice, one that the new practice will displace. New knowledge and practices may be successfully diffused, *i.e.* made known to their target audience, but then for a range of reasons are often not adopted.

6) *Implementation*

Adoption is a necessary but far from sufficient condition for the application of new knowledge or practice. Adoption involves a willingness to change, but a wide range of barriers may impede successful implementation, *e.g.*:

– Lack of opportunity to implement.

– Practical problems and constraints e.g. inadequate resources, time.

– Lack of social support to sustain commitment.

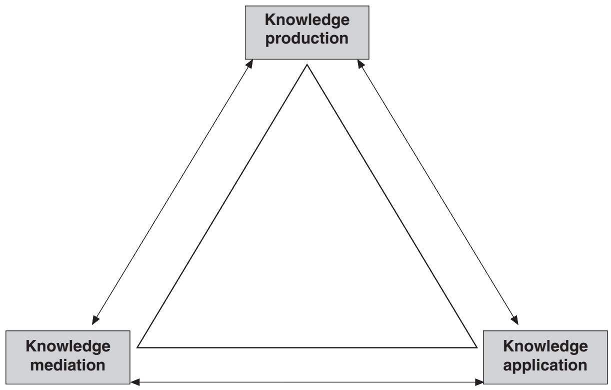
7) *Institutionalisation*

This is perhaps the most complex process, for it involves the knowledge or practice moving from being an innovation to becoming a sustained, routine practice that is accepted as "normal". An innovation is not institutionalised until it endures beyond the time/presence of those who originally adopted it.

... second, because they do not in practice proceed sequentially, but there is feedback from one to another, suggesting an interactive rather than a linear model.

The second problem with the linear model is that these seven processes tend to be seen as *stages*. Not all the processes are necessarily involved in all cases of dissemination and application, nor do they by any means always follow in a neat sequence. In the linear model the processes take a logical order; in practice, feedback loops and overlaps between the processes yield a different sequence. Indeed, as von Hippel demonstrated in the 1970s, users may play a key, or even dominant, role in shaping innovation (summarised in von Hippel, 1988). So a more appropriate model is non-linear – interactive

Figure 2. **An interactive model**



(Lundvall, 1988) or iterative, "in which interdependence and interaction between the elements in the system is one of the most important characteristics" (Edquist, 1997). In these models (Figure 2), the three basic processes can influence one another and different actors contribute to these interactions at various points in time. The terminology "production, mediation and use" of knowledge in this chapter should not be interpreted as a commitment to linearity.

Indeed, this chapter will demonstrate how non-linear models have become important in each of the three sectors. The issues in, and models of, the production, mediation and dissemination of knowledge in each of the three sectors are now examined in turn, beginning with teaching. The sectors are then compared and contrasted in order to illuminate developments in the professions in the knowledge economy, with special reference to education.

Knowledge in the education sector

Knowledge about teaching is obscure and disputed; there is thus no consensus about how teachers should be trained or about the role of educational research.

It is perhaps one of the great ironies of the teaching profession that whilst formal education is patently a knowledge-intensive activity, the nature of the knowledge-base of those charged with responsibility for it is both obscure and a constant subject of debate. This has two important consequences. First, there is lack of agreement within and between countries about the content, structure and length of initial teacher training and the continuing professional development of teachers. Secondly, the direction, quality and value of research and development in education is increasingly questioned.

Specialised teachers tend to be trained in their speciality; generalists in the "foundation" disciplines of education…

Where the content of the teacher's knowledge is highly specialised, namely in upper secondary and higher education, professional competence is commonly held to lie in mastery of that specialised subject. At least until recently, little attention has been given to the university teacher's teaching skills – indeed, there is normally no need for a university teacher to obtain a qualification as a teacher. When the content of the teacher's knowledge has a relatively small specialised element, as with early years teachers, where the content has been traditionally defined as basic literacy and numeracy plus elementary social skills, the training has focused on pedagogy rather than curriculum content. For such teachers, some form of qualification is regarded as essential, but much of the content of training has in the last thirty years consisted of the study of the disciplines that inform professional practice – psychology, sociology, philosophy, usually called the foundation disciplines of education.

... which are not based on the study of education itself...

The academic study of education, and associated educational research, has thus been deeply informed by these disciplines, most of whose content did not arise from the study of educational phenomena or problems, but from the concepts, theories and research that preoccupy the "mainstream" practitioners of these three disciplines. Psychologists are more interested in learning and memory than in formal education; sociologists have studied many types of organisation, only a minority of which are schools and universities; and whilst an important branch of philosophy is epistemology, only parts of it deal with children's knowledge, its nature and acquisition.

... and multi-disciplinary study does not tend to lead to an integrated cross-disciplinary framework for studying education.

University Schools of Education, like other professional schools (architecture, medicine, engineering, social work, social administration), deal with a *field of study* rather than a single *discipline* and the academic staff come from different disciplines leading to an absence of a single overarching discipline or a shared conceptual framework. Though it is sometimes argued that this produces an *inter-disciplinary* context for the promotion of novel approaches to the phenomena in the field of study, the more common situation is one of *multi-disciplinarity* with relatively low levels of interaction or integration among academic staff from different disciplinary backgrounds, and as a consequence there is a relatively low level of intellectual and social integration among the academic staff.

Schools of Education tend to be staffed on the one hand by teaching specialists with experience of practice...

Although Schools of Education vary considerably in size, composition and function, in most there are two relatively distinctive groups or cultures. In the first, the orientation is to teacher education, usually to initial teacher training in particular but also to courses and higher degrees directed mainly at practising teachers. The background of these academic staff is lengthy and distinguished professional service in schools, with relatively little experience of the foundation disciplines of education (psychology, sociology, philosophy and history) or educational research. They think of themselves primarily as "educators", as teachers of teachers, a continuing part of the teaching profession, though based in higher education. They justify their existence in terms of their contribution to the improvement of the quality of teaching in schools and they write for professional journals read by practising teachers.

... and on the other by academic psychologists, sociologists and others in "foundation disciplines"...

The background of staff in the second group is likely to be in a foundation discipline, and sometimes without practical experience as a schoolteacher. Their social identity revolves around their specialist discipline and they think of themselves as academics and researchers as well as (and sometimes rather than) teachers of teachers. They justify their existence in terms of their scholarly achievements rather than their direct contribution to improving the quality of teaching in schools. They may write sometimes for professional journals, but see their most important writing as papers at academic conferences and articles in scholarly books and journals.

... with optimism from the 1960s that the latter group could apply theoretical social science to education...

Thirty years ago there was considerable optimism about the potential of applying the social sciences to educational phenomena and problems and confidence that a science of teaching was being created. As the qualifications of teachers in primary education were raised, it was these subjects, not the subjects of the school curriculum, that were to provide the knowledge-base of teachers for subsequent application in the practice of teaching. Apprenticeship schemes moved into disfavour, since experienced practitioners in schools were unfamiliar with the theory and so could not help novices to apply it to innovative practice. Old teachers, in short, could not be trusted with the training of new teachers.

... but in practice the irrelevance to every day teaching brought theories into disrepute...

Not surprisingly, perhaps, many trainee teachers have questioned the relevance of this "theory" to their professional practice. For most found the theory they learned in initial training very difficult to apply in practice. To survive as new teachers, they adapted to the working culture of experienced teachers. "Theory" soon came to have negative connotations: research was seen by many teachers as largely incomprehensible and irrelevant to the solution of their day-to-day problems.

... while at the same time political demands for educational improvement grew...

It is precisely this tension between theory and practice in teacher education, and between educational research and educational improvement, which has been highlighted by changing policy demands on the profession. For concurrently with the growth of the academic study of, and research into, education has been increasing political and public concern over educational "standards" – the levels of students' academic achievement and what reforms might be needed to improve the quality of educational provision. There have been two main consequences.

... with the result that, first, policy has made initial training more practice-based...

First, there has been a strong movement, led by politicians and policy makers, not university-based teacher educationists, towards increasing the extent to which both initial teacher training (as well as the continuing professional development) should be school-based and shaped by experienced teachers. It is, in effect, a rehabilitation of the professional apprenticeship, which brings the training of teachers more into line with that of doctors and engineers. University-based educationists, who prefer to speak of teacher education rather than teacher training, construe these moves as the de-professionalisation of teachers.

... and second, educational research is being at least reassessed, and at most derided as useless...

Secondly, educational research has come under very close scrutiny in several countries (McGaw *et al.*, 1992; OECD, 1995; Kloprogge *et al.*, 1995; Nisbet, 1995; OECD, 1995; Hargreaves, 1996; Hegarty, 1997; Hillage *et al.*, 1998; Rudduck and McIntyre, 1998). Although all these reviews note the high quality of the best educational research, and although educational research has been more valued and used in some countries, such as Sweden, than in others, the overall tone is critical, as indicated in the following comments:

> It is widely recognised that there are large lacunae between researchers and practitioners in education (OECD, 1995).
>
> If the purpose of educational research is (...) to inform educational decisions and educational actions, then our overall conclusion is that the actions and decisions of policy-makers and practitioners are insufficiently informed by research (...). The lack of an effective dialogue and understanding between researchers, policy-makers and practitioners is illustrated by the fact that while most of the researchers felt that the balance of the research agenda was too skewed towards policy and practice, the practitioners and policy-makers thought the opposite (Hillage *et al.*, 1998).
>
> Educational research has not fulfilled its role in the effort to improve schools, perhaps because it runs into too much scepticism from practitioners and policy makers (Assistant Secretary for Educational Research and Improvement, US Department of Education in Finn, 1988).
>
> Schools in the Netherlands hardly play a role in setting the research agenda (...). There is no lack of magazines and periodicals that regularly write about research. On the other hand, according to some surveys, only a small minority of teachers actually read educational periodicals (...) (Kloprogge *et al.*, 1995).

We now have a virtual catalogue of reasons for this perceived lack of usefulness of educational research. The reasons hypothesised for the apparent failure of research to influence teaching can be grouped into four general hypotheses: *a*) The research itself is not sufficiently *persuasive or authoritative*; the quality of educational studies has not been high enough to provide compelling, unambiguous or authoritative results to practitioners; *b*) The research has not been *relevant* to practice. It has not been sufficiently practical, it has not addressed teachers' questions, nor has it adequately acknowledged their constraints; *c*) Ideas from research have not been *accessible to teachers*; *d*) The education system is itself intractable and unable to change, or it is conversely inherently unstable, overly susceptible to fads, and consequently unable to engage in systematic change. Either of these characteristics (...) render it incapable of responding reliably to research (Kennedy, 1997).

... but agreement that there is a problem is not matched by consensus on a solution.

Evidently we see here a collapse of the earlier optimism that there could be a science of teaching or that education policy would be research-based (to take the strong form) or alternatively that both practitioners and policy makers would commonly be helped in finding solutions to their problems by social science and educational research associated with it (to take the weaker form). That something has gone wrong is conceded by most. Exactly what has gone wrong and what should be done to improve matters continues to be hotly debated.

One difficulty is that teachers lack a clear scientific knowledge base, and rely largely on personal experience...

While this debate continues, however, it is undeniable that the knowledge-base of teachers is very unlike that of either engineers or doctors and nurses, in that there is neither a corpus of scientific knowledge to underpin it nor a body of research evidence about "what works" to inform it (for an elaboration, see Hargreaves in Part II). The teacher's knowledge-base is acquired largely through personal experience of working on one's own in the classroom, aided by discussion with colleagues. Things have purportedly changed little since those two noted and unsurpassed observers of classroom teachers reported a generation ago that:

> One of the most notable features of teacher talk is the absence of a technical vocabulary. Unlike professional encounters between doctors, lawyers, garage mechanics and astrophysicists, when teachers talk together almost any reasonably intelligent adult can listen in and comprehend what is being said (...). [This] absence of technical terms is related to another characteristic of teacher talk: its conceptual simplicity. Not only do teachers avoid elaborate words, they also seem to shun elaborate ideas (...). This is the tendency to approach educational affairs intuitively rather than rationally. When called upon to justify their professional decisions, for example, my informants often declared that their classroom behaviour was based more on impulse and feeling than on reflection and thought (Jackson, 1968).

or that:

> Individual [teachers] must resolve recurrent problems largely unaided by systematic, relevant knowledge (...). Teaching has not been subjected to the sustained, empirical and practice-oriented inquiry into problems and alternatives which we find in university-based professions. It has been permitted to remain evanescent; there is no equivalent to the recording found in surgical cases, law cases and physical models of engineering and architectural achievement. Such records, coupled with commentaries and

> critiques of highly trained professors, allow new generations to pick up where earlier ones finished (…). [T]o an astonishing degree the beginner in teaching must start afresh, uninformed about prior solutions and alternative approaches to recurring practical problems. What student [teachers] learn about teaching, then, is intuitive and imitative rather than explicit and analytical; it is based on individual personalities rather than pedagogical principles (…). One's personal predispositions are not only relevant but, in fact, stand at the core of becoming a teacher (Lortie, 1975).

At the same time, most teachers have, especially in recent years, been the target of much material from ministries, advisory bodies, academics and colleagues that relates to their professional activities. All these are sources of mediation from research and from advances in the social sciences that influence the way both professional problems and their possible solution are conceptualised. To what extent, in what way and with what effect (beneficial or otherwise) such mediations operate remains a mystery. It seems likely that much of this is not absorbed by many teachers, or is retained by them at the level of rhetoric or espoused theory but fails to penetrate everyday professional practice. The art of teaching probably remains largely self-taught through individual trial-and-error learning in the busy but professionally isolated world of the classroom where there is relatively little opportunity for reflection. In consequence the teacher's knowledge-base is unusually rich in personal, tacit know-how but impoverished in terms of shared, codified knowledge.

… although increasingly they are given materials to influence their work, but it is unclear how far these transform shared knowledge into changed practice…

It is little wonder, then, that the pressure of reforms directed at rapid professional improvement and the raising of students' measured achievements is widely interpreted by teachers as threatening and demoralising, because the ways in which demands for higher standards of teaching and learning could, even in principle, be achieved are far from clear to them. Frustrated policy makers look outside educational circles – teachers, educational administrators, and the university-based educationists and teacher trainers – for radical ideas about what is to be done.

… and in the confusion teachers still rely on personal tacit knowledge, but fell attacked.

What is the situation in other sectors? Do they provide clues to better ways of working in education?

Knowledge in the health sector

The health sector is large, accounting for between 6-12% of GDP across OECD countries (as against 4-8% for the education sector). Though use of health services varies between nations (see Kervasdoué in Part II), public expectations of them have everywhere risen dramatically since 1950 and the trend is still upwards. Fresh demands arise from the appearance of new drugs and the invention of new technology, from advances in prevention and diagnosis as well as therapy, and from new categories of demand, such as care of the elderly. What were once seen as social or educational problems easily become "medicalised", as the development of Viagra or concern with conditions such as attention deficit hyperactivity disorder (ADHD) illustrate. At the political level the major issues of policy relate to:

Health is a big sector confronted by big issues…

– The proportion of national wealth to be devoted to health.

– The allocation of resources within segments of overall health provision.

– The determination of priorities.

– The balance between preventive and therapeutic medicine.

– The balance between private and public provision and financing.

– The creation of structures and mechanisms to maximise efficiency.

– The education and training of health personnel, including administrative staff.

– National differences in all the above.

All these areas are potentially focal points for knowledge creation and innovation: they are also potentially points of considerable conflict, especially between policy makers and those involved in service delivery.

... characterised by many actors whose relationships shape knowledge production and use, particularly as patients' knowledge and decisions grow in importance.

As in the case of engineering, the health sector includes a range of key actors. Bauer's "7-p" model (see his article in Part II) identifies seven principal actors – patients, providers, practitioners, payers, purchasers, pharmaceutical industry, professors. The interactions among these actors shape what counts as relevant knowledge as well as how it is produced, mediated and used. The widely felt need to restrain the escalating growth of public spending on health, for instance, stimulates the production of new knowledge about health care management and how that is best used, though this risks an increase in tension between managers (bureaucrats) and professionals (doctors and nurses). Whilst patients have traditionally been passive receivers of medical knowledge in the form of instruction and treatment by doctors and nurses, the wider dissemination of medical and clinical knowledge among patients can lead particular groups or individuals to inform themselves and to take issue with the professional practitioners (Epstein, 1996). Indeed, as the public becomes better informed through popular medical books, newspaper articles and television plays about hospitals, a new distribution of knowledge, and thus of power, is reflected in physicians' changing relationships with patients, which become arenas for negotiation, rather than direction, over both diagnosis and treatment. Increasingly patients make the decisions, based on advice from medical staff, part of whose role is to supply the evidence relevant to any decision or choice. Judging the levels of education and anxiety in the patient becomes an important professional skill in such negotiations with patients, especially where the patient's consent too complicated or unpleasant forms of investigation or treatment are involved.

Medical knowledge draws from many disciplines, and despite huge growth continues to have major gaps.

The sources of new knowledge in medicine are exceedingly wide. One source comes from basic research in mainstream science departments in universities, and the potential medical applications may not be recognised immediately. Another source lies in physics and engineering, rather than biology or chemistry, since the reliance on technological – and now nano-technological – developments for diagnosis and treatment increases steadily. Both Aids and BSE/Kreuzfeld-Jacob disease draw public attention to the existence of large pools of ignorance despite the huge advances in medical knowledge and skill, ones which can be remedied only by scientists coming from a range of backgrounds collaborating to generate new knowledge and means of applying it rapidly and effectively.

Pharmaceutical companies' research role is growing relative to public research, but in some fields improvements in processes are more important than new drugs.

The power of the pharmaceutical industry has grown enormously. The larger companies can invest lavishly in basic research, either in-house or in university departments, since the potential returns on investment in some areas are exceptionally high in global markets. Although public investment in medical research remains strong, its relative importance is in decline and the research role of many medical practitioners may amount to relatively low-level participation in drug trials. Yet this does not by any means apply to all of the fifty or more recognised specialities (plus as many para-medical occupations), some of which are less influenced by the pharmaceutical industry than others.

Many surgical specialities, for example, may be more affected by technological advances (*e.g.* in prostheses or scanning techniques) or by new operative procedures invented by leading surgeons. At the same time, advances in surgery often depend on innovation in other fields, as for example the dependence of transplant surgery on progress in immunology, which itself depends on pharmaceutical advances.

New medical knowledge increasingly emanates from specialists working alone or in groups; this can undermine the role of general practitioners…

The increasing specialisation that arises from the rapid expansion in knowledge among medical staff has consequences. Trust in, and deference towards, general medical practitioners from patients may decline; patients whose presenting condition is not readily identified can be passed from specialist to specialist; and whilst specialisation increases some boundaries, it may also blur others (*e.g.* cardiologists, as physicians, insert pace-makers or manage angioplasty, which might be regarded as invasive techniques that should properly fall to surgeons). At the same time, many advances require medical specialists to collaborate with one another as well as with technologists or mainstream scientists (*e.g.* chemists, geneticists). Specialisation can isolate specialists as well as forcing them into collaborations, and new knowledge is produced by both routes.

… who find it hard to keep track of a growing mass of medical knowledge, and therefore create individualised knowledge bases.

The general medical practitioner is placed at a considerable disadvantage by the rapid growth of medical knowledge and its associated specialisation, since it is impossible to keep track of advances in diagnosis and treatment across the whole health field. The sheer number of drugs, often marketed in various combinations and under a variety of names, means that general practitioners need constant and sophisticated guidance and help with prescription. At OECD seminar in Paris (see Foreword to this volume, p. 3), Jean de Kervasdoué noted that in France there are about 7 000 prescribable medicines, made up from about 3 500 ingredients, which would require a huge feat of memory from physicians seeking to have such knowledge at their fingertips. In practice, they work with a restricted range of personal preferences influenced by a range of factors, including individual clinical experience and the advertising of drug companies. As medical knowledge advances rapidly, it becomes progressively difficult for doctors to share a common knowledge-base, especially at the general practitioner level.

An authoritative scientific grounding for medical practice is a relatively recent concept…

Medicine is generally perceived to be grounded in the natural sciences, from which it draws much of its authority. It was not always so. The practice of medicine has for most of its history proceeded

> (…) by sheer guesswork and the crudest sort of empiricism (…). Virtually anything that could be thought up for the treatment of disease was tried out at one time or another, and, once tried, lasted decades or even centuries before being given up (…). [This was] an irresponsible kind of human experimentation, based on nothing but trial and error and usually resulting in precisely that sequence (…). Then, sometime in the early nineteenth century, it was realised by a few of the leading figures in medicine that almost all of the complicated treatments then available did not work [and] that most of them actually did more harm than good (Thomas, 1977).

> The discovery of antibiotics, which could produce an outright cure, produced a new confidence in medical knowledge and its application.

> Overnight we became optimists, enthusiasts. The realisation that disease could be turned around by treatment (…) was a totally new idea 40 years ago (*ibid.*).

... and today, contrary to perceptions, each practitioner applies medical knowledge differently (although variations may be smaller among specialists)...

Work at the Copenhagen Institute of Social Medicine (Andersen and Mooney, 1990) reveals the contrast between popular conceptions and the stark realities of contemporary variations in medical practice.

> Medical practice – in contrast to most other social practices – has the image of being based on solid scientific grounds. We have all been brought up with an understanding that medical care was established through a continual process of interaction between medical practice and medical science, with ever more sophisticated knowledge becoming available to the defenders of our precious health, the medical profession. The development of present-day medical sciences has taken place in a very explicitly international context, which has contributed substantially to the image of modern health care as being based on a unified body of comprehensive scientific knowledge. The perception of modern medical practice as a coherent, scientifically based activity has, by and large, been accompanied by a general fascination by the technological advanced level of new innovations.

However, it has repeatedly been demonstrated that individual patients with identical conditions are treated in radically different ways by highly qualified physicians claiming to subscribe to the same corpus of scientific knowledge. New disciplines in health services research point to the existence of enormous differences from one place to another in the way that current medical practice is conducted. A new picture of modern medical practice emerges in which

> (...) highly significant variations in treatment methods seems to be the rule rather than the exception in modern medical care. The scientific basis of many prevailing medical interventions is to a large extent inadequately developed, and many common treatments have been launched without ever having been subjected to thorough scientific evaluation (...). A more or less mythological image of medical care as a professionally homogeneous, scientifically based activity is giving way to a more realistic, but far more challenging, actuality of variability and uncertainty (...). The development of health services research is gradually providing more and more visible evidence about the details of health service utilisation (...). Providers, consumers and administrators are becoming more knowledgeable as a result (*ibid.*).

It is possible that specialists will have a larger shared knowledge-base than general practitioners, in that there is a much narrower field of work that has to be tracked and a limited number of highly specialised, international journals provide for this. It is part of the culture of medical specialisation for specialists to disavow medical knowledge of anything outside their own speciality.

... hence a quest for more systematic evidence of "what works", and its use by doctors.

The acknowledgement of this indefensible diversity of treatment, combined with the recognition that perhaps no more than 20% of medical practices have been adequately evaluated (Eddy, 1994) has stimulated the search for new forms of knowledge other than "basic" medical research, namely research into the effectiveness of clinical practices – "what works" – and the distribution and use of such professional knowledge by doctors. It is here that we find the foundations of what is now often called "evidence-based medicine" (Sackett, 1996), which also takes account of the fact that many disorders improve when left untreated. The object, therefore, is to find convincing evidence that a treatment improves health when compared with no treatment, or does so more effectively than an alternative treatment, and that the benefit caused by the treatment clearly outweighs any harmful side-effects.

While random tests of treatments provide the most conclusive evidence, there is pressure from patients not to wait for such results but to go on the best available…

To advocates of evidence-based medicine, the randomised controlled trial (RCT) is at the head of any rank order of types of evidence (Maynard and Chalmers, 1997). Though the RCT is now the gold standard, it is only following the trial of the efficacy of streptomycin in the treatment of pulmonary tuberculosis in the late 1940s that it has been so accepted. But patient deference to physicians has declined since then. Today, informed lay persons, such as the activists in the Aids crisis in the United States, have little patience with the leisurely pursuit of truth by physicians committed to scientific niceties, being willing instead to settle for today's best guess about what works (Epstein, 1996). Moreover current sensitivity to the ethical issues affecting the conduct of trials illustrates the changed relationship between doctor and patient.

… so doctors need a system of access to a wide range of imperfect knowledge, helping them act as intermediaries between commercial suppliers and end-users…

From the physician's point of view, the challenge is three-fold: to find ways of providing an up-to-date and authoritative review of the evidence which takes account of the fact that much medical research is deeply flawed; reporting that overview in a form that is easily understood by general medical practitioners as well as specialists; and then making it readily available to them, which is now a possibility through ICT. Indeed, the Cochrane Collaboration and related developments are directed to just such an end. The extent to which this will weaken the power of pharmaceutical companies to influence physicians through advertising and brand recognition remains to be seen. At the same time such information is likely to be increasingly in the public domain, and so accessible to, and more easily understood by, patients and other lay people, who may use the knowledge to pursue their own interests which may not be compatible with those of the medical practitioners. The medical practitioner stands as the intermediary between those who produce knowledge and extol its products and consumers with rising expectations and increased (if still limited) knowledge.

… and* ICT *will be an invaluable tool in this quest, though it will not replace human contacts.

Since most medical practitioners in developed economies now have ready access to ICT, this will increasingly be the medium by which new knowledge is disseminated among the profession. Though inter-personal contact, as in conferences, remains important, doctors are not in general a highly mobile profession and reliance on the virtual communities now being generated through ICT will increase. In the same way, the use of ICT to store medical records and the severe decline in film-based radiography, open the doors to new forms of research through ICT to replace the reliance on case notes and the vagaries of medical records. The dissemination of practical know-how continues to rely heavily on personal contact, for surgical techniques, like the art of cooking, are not adequately disseminated by recipe books alone: observing a demonstration, assisting and working alongside the experienced practitioner are ways to achieve practical know-how that go beyond any written account of the formal knowledge involved.

Medical education is increasingly giving practical training concurrently with theoretical instruction…

Changes in medical education, both initial and continuing, may well change how physicians cope with this more complex world of professional practice. Academic pre-clinical education and clinical training are increasingly structured in concurrent rather than consecutive chunks, and the teaching is problem-oriented rather than didactic in style. In principle these approaches help to bridge the gap between "theory" and "practice", since it is well known that trainee doctors often possess knowledge needed in a clinical situation but do not always perceive its relevance and value.

Further, communication and inter-personal skills, relevant to interactions among health care staff as well as with patients and their friends and relatives, can be acquired alongside the formal knowledge, instead of being a later adjunct to it.

… with qualified staff pursuing both academic study and on-the-job training, either by watching and listening or (best practice) more planned instruction…

The post-qualification training of medical specialists is similarly divided, between on the one hand academic study for higher qualifications, much of which is done through formal teaching, courses and private study, and on the other hand practical, on-the-job training (OJT) within a speciality under the supervision of an expert. There are two major forms of OJT – by osmosis or coaching. In the *osmosis* model, the trainee doctor somehow "picks up" relevant knowledge, skills and understanding during the daily round of service delivery. Much is acquired by watching and listening to colleagues and superiors, as well as directly through "hands on" experience. It is an unplanned and unsystematic yet pervasive feature of professional learning. It is very important in the acquisition of tacit knowledge, but less good on transmitting formal knowledge or on integrating the codified and tacit. In the *coaching* model, the teaching and learning are intentional and planned and much less opportunistic. The coach demonstrates and explains the relevant skills; opportunities for imitation and practice are provided; the trainee is provided with feedback and support in learning. Both models are forms of apprenticeship – a topic to be discussed in the next section – but it is the coaching version which exemplifies best practice, not least because it is here that the integration of formal and tacit knowledge takes its most sophisticated form. It is here that the theory of situated learning (see Hargreaves in Part II and Chapter 3) proves itself to be such a rich resource on how knowledge is acquired in professional training. Many doctors describe medical training as a form of apprenticeship, and in this they reveal the common ground with engineers about how a craft is acquired.

… and needing more than ever to update medical knowledge and competence.

Today there is a concern with the importance of the professional development of doctors – the content, form and frequency of continuing medical education (CME). This reflects not only the rapid growth in medical knowledge and the need for doctors to keep reasonably up-to-date, but also the need for the practitioner's medical competence to be demonstrable. With the increase in the accountability of doctors, and the exposure of cases of incompetence and negligence, both professional accreditation bodies and insurance companies need evidence of competence checks and familiarity with recent developments. There is less external pressure on engineers in these matters, since the test of an engineer's knowledge and skill is for the most part made not in terms of public accountability but from within the firm, in terms of a continuing capacity to design and innovate effectively, which of course depend in part on forms of continuing education and training.

Knowledge in the engineering sector

The economic importance of innovation in engineering makes both university-industry links and the training of engineers of great significance.

Economic development and growth depend in part on the effective application of new knowledge. The ability of industry to innovate plays an important role in gaining comparative advantage in highly competitive markets. In the engineering sector, therefore, it is vital to uncover how new ideas and knowledge are produced and then translated into the design for new goods or services, or ones of higher quality, or a shorter and cheaper manufacturing lifecycle. Such an enquiry immediately opens up two key issues: the relationship between universities and industrial firms in the development of innovation; and the role of each in the education and training of engineers.

A linear model leading from university science to industrial production only sometimes applies in this sector, for a variety of reasons…

The evidence from the engineering sector shows that the classical or linear model of innovation, whereby academic scientists in universities create new ideas which are then mediated to industry-based engineers who apply this knowledge in the production of new goods, sometimes works, but often does not. The linear model is a simplistic and misleading account of practice, and probably of principle, for several reasons:

- The knowledge of the academic researcher is predominantly of an explicit kind directed towards a contribution to codified scientific knowledge. Whilst industrial engineers possess a core of such knowledge in their knowledge-base, much of their working knowledge consists of practical know-how, which is rich in tacit knowledge.
- Knowledge production takes place in industry in R&D units as well as in universities.
- Knowledge is mediated between groups in many ways, not merely through formal technology transfer.
- Engineering enterprises are highly heterogeneous, in terms of size (from small to large multi-national), of specialisation (*e.g.* mechanical engineering, bio-technology), of location and of culture (both national and organisational). Such substantial differences affect the relationships among firms and between firms and universities.

… instead one should take account of:

In consequence, there is no single way by which the process of the production, mediation and use of knowledge can be adequately described, and the simple linear model becomes increasingly nugatory. Among the factors that alternative models need to take into account are the following:

– commercial input to design,

- Since a new product has to sell at a reasonable price, the design process cannot, without substantial risk, proceed very far without the tempering advice of those who will manufacture it.

– feedbacks from users,

- Markets and consumers can play a key role in shaping the nature of an innovation and determining its commercial success. A product price assumed to be acceptable on the market may become part of the design of the product. This "feed-back loop" from the market often leads to a refinement of any new knowledge and the way it shapes design.

– non-university knowledge,

- Although new knowledge created in universities is often a contributing element in innovation, such knowledge interacts with other forms of knowledge, such as industry-generated research as well as the stores of practical know-how, often tacit, held by practising engineers.

– university-industry interaction,

- Closer interaction between universities and industry, and joint R&D projects, especially where supported by government initiatives, can enhance national capacity for successful innovation. Link organisations and science parks work in this way (see Eliasson, Part II on "competence blocs"). It is through such interactions that user firms can influence the research agendas of the academic community.

– movement of knowledge embodied in people,

- Much knowledge, especially in tacit forms, is embodied in individuals whose movement from firm to firm, or between industry and academe, is a powerful form of mediation and dissemination. The particular combination of people in a particular place at a particular time may be more important for successful knowledge production than the type of location. Increasingly, gifted academic researchers are tempted into posts in industry or establish companies of their own, perhaps in collaboration with experienced entrepreneurs. New knowledge is thus carried and transmitted through elaborate and constantly shifting networks of people.

– and knowledge management in organisations…

– Knowledge creation is less a matter of location than of interaction between different kinds of knowledge and how the process of knowledge creation is managed and supported, wherever it takes place. Here Nonaka and Takeuchi's analysis of *The Knowledge-Creating Company* (1995) is of great significance, and probably in sectors other than engineering

… creating an interactive model.

The *linear* model is thus displaced by a range of *interactive* models which reflect complicated forms of negotiation and processes of learning embedded in interactions between the domains of science and technology, interactions between organisations, interactions between people, and interactions between kinds of knowledge.

In the knowledge-intensive pharmaceutical industry, such interactions have recently shaped the industrial structure itself.

The pharmaceutical industry provides an example of these changes. Advances in molecular biology and genetic engineering have influenced pharmaceutical research in many ways, including the prediction of drug failures, that is, those which prove to be ineffective. This is important in that in the past drugs that were relatively ineffective could remain on the market because there was no hard evidence of their ineffectiveness. Since there will be fewer drugs of greater quality, research and commercial success are essential to pay back soaring R&D costs. The consequence has been frequent mergers to produce the giant corporations of today. At the same time, high quality research is often found in much smaller and more informal organisations. Large firms thus become linked externally to small biotechnology companies, universities and research institutes, which have the advantage in knowledge production, and the large firms undertake the large-scale development and commercialisation that are beyond the resources of small units (Gambardela, 1995). Since R&D costs in this industry are so high, companies need to sell a successful product in world-wide markets. Globalisation allows the corporations to tap scarce scientific and technical talent by locating specialised research laboratories in countries with specialised expertise (Howells and Neary, 1995), thus producing cross-national networking.

But university-business links create tensions, especially over ownership of knowledge…

Shaping effective interaction between universities and firms is not easily achieved. There are cultural pressures on university researchers to engage in "basic" scientific research that carries high status in the academic community through publication in prestigious academic journals. Industrial firms are less keen to channel new knowledge into public documents that might inform competitors, and prefer private or restricted applications that confer financial returns, especially in the earliest stages of entry into the market. There is also the growing problem of ownership of intellectual property rights.

… and in sectors such as mechanical engineering, firms often find it easier to generate knowledge internally or in collaboration with competitors…

The desirability of interaction between universities and firms varies considerably. Bio-technology firms require close partnership with university laboratories where high quality research is conducted, whereas for mechanical engineering firms the "basic" research favoured in universities is usually less important. Large firms can rely much more on their internal R&D departments – which can recruit able researchers and so serve, as Eliasson (Part II) points out, as a technical university – than can small and medium size enterprises, with low levels of in-house research capacity. Moreover there is a recognition that no firm, however large, can generate all the new knowledge that is either needed or might be of value, so a degree of co-operation and exchange between firms is increasingly common, though some knowledge is usually protected until its potential value can be assessed and, where appropriate, exploited. The co-operative sharing of knowledge is not incompatible with competition (Fruin, 1992): indeed, it may be essential to competition, since without such sharing many firms would not survive thus jeopardising the industry as a whole. This is now being understood by governments.

> Successful businesses compete aggressively (...). But alongside competition, businesses need to be willing to collaborate – to learn from others, including their competitors. Successful businesses improve their performance continuously, through adapting ideas and techniques developed outside the business and promoting co-operation within the business. Even businesses that regard themselves as world-class have made extraordinary improvements in productivity and profitability from benchmarking as a result of changing the ways they work. In a knowledge driven economy, partnership is essential to competition. to exploit our capabilities in people and technologies, businesses have to collaborate across sectors, throughout regions and with education (UK Department of Trade and Industry, 1998).

... blurring distinctions between scientific and industrial knowledge.

The boundaries between universities and firms, between basic and applied research, between scientific knowledge and technological application are thus becoming increasingly diffuse. Where a research project is located no longer provides a clear indication of its character. At the same time, the organisation of R&D in engineering firms is the object of fundamental re-examination.

For a firm to produce and use knowledge, it needs to manage it effectively – which requires particular industrial structures and cultures...

Cultural factors within firms are now recognised as being of major importance in the successful production and exploitation of new knowledge, as against crude indices of the size of R&D departments or R&D expenditure. The capacity of companies to create and use knowledge lies not so much in their possession of knowledge or technical expertise but in the way the firm is structured, managed and led. Of particular importance is the capacity of the firm to audit and deploy effectively its intellectual capital (knowledge and skill) and social capital (trust, collaboration): knowledge management is rapidly assuming salience in industrial and business management circles. The internal culture needs a strong outward orientation – in Cohen and Levinthal's (1990) terms, an "absorptive capacity" to recognise, assimilate and exploit external information and knowledge that can be turned to advantage within the firm.

... and can also depend on national cultures. In pursuit of "intelligent manufacturing", Japan has launched a global effort to transmit tacit knowledge.

Cultural differences between countries are also relevant (*cf.* Hofstede, 1991; Hampden-Turner and Trompenaars, 1993). National differences in innovation systems have been examined (Lundvall, 1992; Nelson, 1993). At the OECD seminar in Tokyo (see Foreword to this volume, p. 3) the Japanese hosts were interested in how their own culture can be developed to enhance the capacity for innovation rather than imitation and the application of imported technology. This is a priority shared by many other countries. A distinction was made between "Toyotism" and "Taylorism", the former taking as its principle the need to think backwards, so that the market shapes design and production, not the other way round. It was also at the initiative of Japan, thanks to Professor Yoshikawa, that the international programme on the intelligent manufacturing system was launched. The aim is to encourage research by the world's leading companies in the new manufacturing system. This global project, involving 350 firms and universities, seeks to make available to all industrial firms the entire body of tacit knowledge involved in the act of production. The hypothesis is that successful firms have had to create large amounts of tacit knowledge in order to succeed and that this knowledge could usefully be captured in an immense database that could be more widely available, thus avoiding the duplication that leads to productivity losses. To what degree tacit knowledge can be made explicit in order to be captured, and then codified and transmitted in trans-cultural forms, is an important but open question. Hitherto it has been widely assumed that tacit knowledge can be acquired, but not taught and learned in an explicit or formal way. In the words of Donald Schön, who has assumed the mantle of the guru in the field of professional education, "The student cannot be taught what he needs to know, but he can be coached" (1987, p. 17).

As the roles of universities and firms overlap, professional knowledge in each is brought into question…

The linear model helped to legitimise the distribution of labour in what novice engineers are supposed to learn in different locations – university and workplace: the argument that at the university the students simply learn the codified science and theory as a preparation to its practical application in the workplace. This is no longer tenable, as is also the case in medical education. Studies of the acquisition of mastery or expertise throw further doubt on this neat allocation of roles between academics and practitioners. Increased understanding of the nature of knowledge and its management in general, and of the process of innovation in particular, raise profound questions about the nature of education and training for the professions.

… for example universities need to prepare students to acquire know-how in work not just know-what and know-why…

At the Tokyo seminar it was reiterated that one of the university's important functions is not merely the production of knowledge itself but shaping the cognitive and social style of its students who will subsequently be involved in its application. A willingness to take risks and an ability to work in trustful collaboration with a range of colleagues are held to be important ingredients of successful innovation and the acquisition of such skills by students may be a critically important aspect of university training. Too little is known about the relation between knowledge acquisition at university through lecturer-student mode, which is so heavily orientated to formal, prepositional and codified knowledge (for this is the basis of both instruction and examination) and knowledge acquisition in work-based settings, which is mainly practical know-how, developed in a master-apprentice mode, with its subtle but vital learning of tacit knowledge.

> To learn by example is to submit to authority. You follow your master because you trust his manner of doing things even when you cannot analyse them and account in detail for its effectiveness. By watching the master and emulating his efforts in the presence of his example, the apprentice unconsciously picks up the rules of the art, including those which are not explicitly known to the master himself. These hidden rules can be assimilated only by a person who surrenders himself to that extent uncritically to the imitation of another. A society which wants to preserve a fund of personal knowledge must submit to tradition (Polanyi, 1958/1978).

… and thus bridge the cultural divide…

This contrast between the two forms of teaching and learning is set out, in a stark but tentative way, in Table 1.

… reflected in education-to-work transition problems, addressed by mentoring, and potentially producing a creative clash generating innovation…

Much more is known about school-based than about work-based teaching and learning; it is only relatively recently that the latter has been the subject of serious treatment (*e.g.* Marsick, 1987; Marsick and Watkins, 1990; Lave and Wenger, 1991; Coffield, 1998). The transition from school to work, or from the university to the practice of a profession, is acknowledged to be a problem from the novice's point of view. In recent years this has led to the growth of *mentoring*, by which an experienced practitioner supports the novice during this period of early on-the-job learning. It is now being recognised that the collision

Table 1. **Schooling *versus* apprenticeship**

In "doing school" Knowledge is....	**In "doing a job" Knowledge is....**
Declarative (facts about...)	procedural (how to...)
Usually explicit	often tacit
easily stated	more easily demonstrated
abstract	concrete
logical	intuitive
"in the mind"	"embedded in action"
an end in itself	a means to an end
remote from application	close to application
learnt sequentially	learnt piecemeal
"hooked" to a text	"hooked" to persons/events
stored in semantic memory	stored in episodic memory
usually fragmented	usually integrated
a stack of information	a stock of experience
something to be remembered	something to be understood
forgotten quickly	forgotten slowly
rehearsed during revision	rehearsed through practice
tested by examinations	tested by performance
a process of acquisition	a process of engagement
weakly related to identity	strongly related to identity
linked to being taught	linked to being coached
This is "learning before doing"	**This is "learning in doing"**

between theoretical or codified knowledge and tacit or practical knowledge may be at the heart of, and an essential contributor to, the process of innovation itself. The interaction between different forms of knowledge are not unfortunate problems to be avoided but serendipitous opportunities to be exploited. Mentoring can be the midwife of innovation.

... but the art of work-based teaching is inadequately understood; it is strongest in countries like Germany with apprenticeship traditions...

Indicators of effective teaching and successful learning in the coaching-apprenticeship mode have been woefully neglected, because these are assumed to be essentially informal processes of the workplace rather than mainstream education in schools, colleges and universities. Advances can be expected from those countries, such as Germany, where classroom teaching and on-the-job training are most integrated and vocational training most fully developed (Scott and Cockrill, 1998). It is arguable that in the absence of further interaction between school-based and work-based learning, the rapid growth of the life-long learning merely reinforces the clash between the learning cultures of school (or university) and work (or professional practice).

... so better bridges are needed between the two learning cultures, aided by two-way education-industry interaction...

Linking the two types of learning is one of the most daunting challenges in the education of professionals. Greater interaction between academe and industry in relation to knowledge production could usefully spill over into the investigation of best practices in the education and training of engineers, with useful lessons of mutual value. Whilst lessons from industry to the university are potentially important for the pre-service training of engineers, lessons from the university to industry will be of growing importance for the lifelong learning and continuing professional development required for practitioner engineers.

... which must involve human mediators not just learning materials...

Conventional forms of mediation, such as written materials or software are important, but much dissemination takes place through a human medium – knowledge-carrying people and their movements and interactions. Significantly, many of these social interactions, either of a face-to-face kind or achieved through the new communication technologies, are highly informal, rather than the official transfer mechanisms of linear models. Job rotation and movement between departments in firms may be designed in the interests of professional development, but they serve as powerful disseminating devices as well as new forms of social mix or cross-functional teams out of which innovation may arise, whether planned or not.

... making it essential to understand more deeply the relationships between universities and firms, and the conditions under which they produce innovation.

Evidently an emerging theme on ways of enhancing the production, mediation and use of knowledge in the engineering sector is the significance of relationships between companies and universities and of the promotion of inter-organisational and inter-personal networks, partnerships and alliances, through which the distinctions between "pure" (or basic) and "applied" become blurred. The linear model misrepresents reality in the engineering sector, where the production of knowledge is increasingly dispersed and heterogeneous. Much remains to be learnt about how to make the successful collaborations on which knowledge creation and innovation rests – see the contribution of Eliasson (Part II). How the nature, strength and impact of these might best be analysed and measured remains a problem. Indeed, much of the evidence for their importance relies on anecdote, description and correlation rather than research which has established causal connections. It seems likely that better qualitative studies will need to precede the development of valid quantitative indicators.

Information and communication technologies: a knowledge tool for all sectors

Concern with the role of ICT pervades sectors like health and education...

In the health and education sectors, there is growing awareness of the potential impact and value (which are very different matters) of ICT, though this has been realised later than in many areas of business and industry. Indeed, in most country ministries concerned with health and education, and their associated organisations, struggle to develop ICT policies and strategies to deal with issues such as:

- How will ICT help to achieve the objectives of these organisations?
- How will they change the pattern of work of professionals and their clients?
- How will members of the organisations be helped to develop positive attitudes towards, and skills with, ICT?
- How will the impact of ICT on organisations and people be monitored?
- Will the inevitable developments in ICT prove to be improvements in the quality of services provided?
- How will value-for-money for the hugely expensive ICT be determined?
- How does ICT change our understanding of knowledge and its production?

... because it redefines how knowledge is codified and accessed.

On this last point, the seminar held at Stanford University discussed how sophisticated information tools can *redefine the boundaries* between explicit, codified knowledge and tacit knowledge. For example, new types of search tools can potentially be used to mimic the librarian who used an understanding of client needs to search for relevant information among a large mass, taking account of such information as the choices made by other users who have historically been interested in items similar to those of the client. Such tools have limitations, however. Codifying all or even most tacit knowledge in the foreseeable future is likely to be impossible in practice, and perhaps in principle.

ICT plays a significant role...

The potential of ICT for developments in education and health are enormous. Indications are provided in several of the papers (for example, Bauer in Part II on tele-medicine). In this chapter, two significant, and apparently contradictory, developments are considered: first, how ICT can increase the use of a centralised, linear model of knowledge production, mediation and use; and secondly, how they can generate new forms of de-centralised networks that will produce and disseminate knowledge in radically new ways.

... both in aiding centralised dissemination of new knowledge (insofar as a linear model applies)...

In societies where key organisations in health (hospitals, surgeries) or education (schools, colleges, universities) can be linked to a central agency or government department, ICT now provides opportunities for knowledge to be disseminated quickly and easily. In short, ICT encourages central policy makers to use linear models by which the role of the centre is to identify effective medical or educational practices and then disseminate them to the relevant professional groups, whose task is to implement the advocated best practices. Policy makers may treat this linear model as less complicated than it really is and so not recognise the many factors which may cause the dissemination to fail.

... and in supporting decentralised networks.

ICT also opens immense possibilities for new forms of *networking*, between individual actors and between organisations. Indeed, what some call the Knowledge Society, others call the Age of the Network (Lipnack and Stamps, 1994), on the grounds that networking will force a radical change in that most striking feature of modernity, the hierarchical organisation.

Many questions are raised by ICT and the new forms of networking they spawn (Coombs *et al.*, 1996).

- Are networks a temporary phenomenon created by the novelty of ICT or does it open radically new ways of conceptualising knowledge production and dissemination?
- Will collaborative networking lead to a revision of understanding of processes of competition and wealth production?
- What changes might this make to our understanding of organisations (firms, hospitals, schools) and the way they are managed?
- Are there differences between countries in the capacity to make productive use of the phenomenon in different sectors of the knowledge economy?
- What are the implications of this for government policy?

To examine some of the implications, let us focus on the sector where hints of answers to these searching questions are most likely to be found.

Knowledge-intensive organisations: a generic concept for all sectors?

Organisations are "knowledge-intensive" only if they harness knowledge rather than just information and contain professionals with unique knowledge stocks...

Within business and industry, the concept of "the knowledge-intensive firm" (in parallel to capital-intensive and labour-intensive firms) is now widespread. Knowledge management, how firms measure and manage their intellectual capital, has become important (Sveiby and Lloyd, 1987; Myers, 1996; OECD, 1996; Roos, Dragonetti and Edvinsson, 1997; Prusak, 1997; Ruggles, 1997; Skyrme and Amidon, 1997; Stewart, 1997; Wiig, 1997; Boisot, 1998; Davenport and Prusak, 1998). But since so many companies necessarily focus on knowledge in a knowledge economy, the term "knowledge-intensive" may quickly lose any descriptive value. Criteria for a definition are needed (Starbuck, 1992). In the present analysis, a knowledge-intensive organisation is assumed to have the following two features:

- The organisation involves intensive use of knowledge (not just information, since knowledge is stock of experience not a flow of information).
- Individual professional members of the organisation have high levels of esoteric knowledge that cannot be widely shared, that is, such members are specialised and cannot readily be substituted for one another.

Most hospitals, schools and high-tech firms thus qualify as knowledge-intensive organisations.

… but such organisations are effective only if they manage knowledge well, as is the case with successful US electronics firms…

To uncover the characteristics of an *effective* knowledge-intensive organisation, we turn to high-tech companies, since it is easier to measure effectiveness (*i.e.* commercial success in a competitive environment) than to measure the effectiveness of either hospitals or schools. Such lessons have been drawn from the research by Jelinek and Schoonhoven (1990), which covered Hewlett-Packard (visited during the Stanford seminar), Intel, Motorola, Texas Instruments and National Semiconductor, firms which have all successfully managed the production and application of new knowledge. As the researchers point out:

> The electronic industry, broadly defined, shapes modern life, profoundly affecting every aspects of our culture and society. Predictions suggest that its influence will continue to grow and deepen; ours is a truly electronic age. Indeed, it is difficult to think of any aspect of life not affected by the pervasive influence of electronics (…). We shall argue that it is characteristic, too, of competitive environments for most businesses in times to come (…). Electronics firms seem not only to tolerate change, but to thrive on it (…). They have a great deal to teach us about the persistent self-renewal that is crucial to their success.

The electronic industry not merely produces new information and communication technologies but uses them in the process of innovation. Knowledge-intensive firms may provide general insights into, or even practical lessons for, other knowledge-intensive organisations, such as those in the health and education sectors.

… which thrive on change, involve all staff in it, and have flat hierarchies and informal social relationships…

Among the characteristics of these successful companies are the following.

- Change is embraced, not tolerated or resisted. Re-organisation is frequent. At the same time, some balancing stability is established. Change and continuity are both needed and are carefully managed.
- There is a constant and explicitly maintained tension between liberty and control, freedom and responsibility.
- Social cohesion is fostered in a "small company" atmosphere. There is a high level of social capital – trust, informality, involvement – "you can talk to anybody here, "if you have an idea, speak up".
- People from different departments or sections, including R&D staff, are brought together in projects.
- Hierarchies and status systems are played down: team-work and collaboration between members of different experience and training are encouraged. Expertise, insight and creativity are more important than seniority: it is local knowledge that counts.
- Junior staff are treated as a potentially rich source of new ideas, whilst more senior people have more organisational credibility.
- Team membership changes often, though with some continuity.
- Boundaries, within the company, and between the company and the outside world, including customers, are blurred, fluid and constantly crossed. Barriers within the company – between research and development, between development and manufacturing, between manufacturing and marketing – are transcended or integrated. Close contact with the external environment is a priority, since the outside

world is a source of knowledge that can be captured through the firm's "absorptive capacity".

– Everybody is expected to contribute to innovation, as a requirement for survival, not a source of "nice ideas". Creativity is not confined to a small, clearly defined group of innovators.
– Knowledgeable action is important: planning documents are almost trivial.
– Knowledge and ideas are actively managed.

... repeated in Japanese electronics firms, but British ones create more closed roles for individuals...

A similar picture emerges from a study of Toshiba (Fruin, 1997) and from a comparison of British and Japanese electronics firms with their different forms of work organisation and approaches to R&D.

> The British approach is based on the principle of individual task and functional specialisation, and the product development cycle is managed on a sequential basis. The job boundaries of the British engineers are much more narrowly defined within their specialist arenas and their role in cross-functional co-ordination is limited. The Japanese approach is based on the principle of undifferentiated job demarcation and decentralised horizontal co-ordination: the product development process is over-lapping. Japanese engineers are expected to engage in direct cross-functional liaisons and in scanning market information. Within this model the co-ordination function becomes partly embedded in the role of engineers. In the Japanese firms, the ability to co-ordinate, to process and share information is regarded as an important part of an engineer's skills and role competence. The two different patterns of co-ordination also define the role of project engineers and the relationship between technical and managerial work (Lam, 1996).

... with projects supervised in a more detached style, compared to Japanese "hands-on" managers, fostering more responsiveness to technology and markets...

In this study there is also a difference between countries in the role of the project head or manager, an important emergent role in many industries. British project managers become specialised co-ordinators, spending a fragmented day in ensuring liaison between functional groups in meetings and crisis management. In consequence they disengage from their design and development work. Japanese project heads engage in strategic planning and decision making, and remain involved technically. Their technical leadership style is "hands on" against the supervisory "arm's length" British approach. The separation between managerial and technical expertise results in low information sharing and trust between the engineers and the project head. By contrast the Japanese form of work organisation integrates technical and managerial roles and fosters a shared division of labour which promotes collective on-the-job learning and enskilling. These engineers are thus more able to adapt creatively to rapidly changing technological and market environments.

... while the pharmaceutical industry has shown how a growing role of science can transform companies' knowledge strategies...

As the pharmaceutical industry has also had to adapt quickly, companies have become knowledge-intensive and knowledge-driven, moving away from merely searching for drugs that work, whether scientifically understood or not, to designing drugs to serve specific functions in relation to particular diseases, which involves the integration of many different knowledge areas. It has been shown (Bierly and Chakrabarti, 1996) that over a fifteen-year period, pharmaceutical companies increased their internal knowledge production and external learning; intensified their R&D; and strengthened their links to mainstream science to achieve knowledge transfer. Firms that in these regards adopted the most aggressive learning strategies tended to be more successful (by the criterion of higher profit margins).

… and ICT in Silicon Valley demonstrates the importance of a mobile, networked market of innovating labour…

The seminar at Stanford University, the heart of the world's most dynamic confluence of high-tech industries, included a discussion with managers at Hewlett-Packard, which confirmed many of the features of successful knowledge-intensive firms described above. Other insights also emerged from this seminar, such as the immense importance in the ICT industries of the *movement of labour* as a dynamic for innovation. In the case of Silicon Valley, which attracts a quarter of all venture capital in the United States, the willingness of individuals to switch jobs, to start up new companies and to learn by failure are important drivers in this industry – and the foundation of networks.

> Job mobility of R&D workers among semiconductor firms is one means of technological information-exchange, and, in some cases, information-exchange may be one reason for job mobility. The close location of firms facilitates freewheeling information-exchange (…). One ought to think of Silicon Valley not as just a geographical place, nor simply as the main centre of the microelectronics industry, nor even as several thousand high tech firms, but as a *network*. As an experienced semiconductor engineer said: "I know someone, and they know someone. But I don't know who they know. The power of this network is that the participants all know it exists" (Rogers and Larsen, 1984).

… but why have conditions here created enduring success since the 1970s, while Boston's "Route 128" has lagged?

Though this was less true during the 1980s, the culture of openness and co-operative practices remained intact – and the consequences were dramatic. In the 1970s two locations in the United States were held to be the world's leading centres of innovation in electronics: Silicon Valley in northern California, and Route 128 near Boston, Massachusetts. Both were renowned for their creativity, entrepreneurship and rapid economic growth – fed by university-based research and military spending. By the early 1980s, things had changed. From the severe downturn, driven in part by intense international competition, one of the two sites emerged with renewed vigour. In Silicon Valley, a new generation of semi-conductor firms and computer start-ups emerged alongside the big companies, such as Hewlett-Packard and Intel. Most of these were small firms, with a staff no bigger than that of a school: 70% had fewer than ten staff and 85% fewer than 50 (Rogers and Larsen, 1984). There were new start-ups too along Route 128, but here it proved difficult to reverse the decline in fortunes. Between 1985 and 1990, the market value of the large technology firms in Silicon valley increased by US$25 billion, but those along Route 128 by just US$1 billion. Despite similar origins and technology, the two regions fared very differently. Why?

It seems the larger number of small, competing yet densely networked firms has created a more dynamic learning environment in the Californian case.

Saxenian's (1994) study offers this explanation.

> Silicon Valley has a regional network-based industrial system that promotes collective learning and flexible adjustment among specialist producers of a complex of related technologies. The region's dense social networks and open labour markets encourage experimentation and entrepreneurship. Companies compete intensely while at the same time learning from one another about changing markets and technologies through informal communication and collaborative practices; and loosely linked team structures encourage horizontal communication among firm divisions and with outside suppliers and customers. The functional boundaries within firms are porous in a network system, as are the boundaries between firms themselves and between firms and local institutions such as trade associations and universities.

> The Route 128 region, in contrast, is dominated by a small number of relatively integrated corporations. Its industrial system is based on independent firms that internalise a wide range of productive activities. Practices of secrecy and corporate loyalty govern relations between firms and their customers, suppliers and competitors, reinforcing a regional culture that encourages stability and self-reliance. Corporate hierarchies ensure that authority remains centralised and information tends to flow vertically. The boundaries between and within firms and between firms and local institutions thus remain far more distinct in this independent firm-based system.

It is evident that these firms use ICT and internal and external networking as key elements in the production and application of new knowledge. These firms' features are not, however, normally characteristic of organisations in the health and education sectors, such as hospitals or schools, yet these surely qualify as knowledge-intensive organisations. One possibility, among others, is that educational organisations that mirror the structure and culture of knowledge-intensive firms will be particularly effective in the production, mediation and use of knowledge in education, and thus be a guide to the schools of tomorrow. A more immediate question is this. Are there good grounds for believing that what is happening in these high-tech industries is part of wider and deeper changes in knowledge societies which are affecting all sectors?

Such ICT-supported networks in high-tech industries are not replicated in health or education. Could they be? Will societies change generally in this direction?

This argument would be stronger if it could be shown that what has been happening in high-tech industries is one aspect of a much deeper and wider trend affecting many forms of the production and application of knowledge. It is this which is suggested by one of the most significant contributions to the analysis of the production of knowledge (Gibbons *et al.*, 1994) which distinguishes between two modes, with particular reference to developments in science and technology. Mode 1 is university-based, pure, disciplinary, homogeneous, expert-led, supply-driven, hierarchical, peer-reviewed. Out of Mode 1 grows Mode 2 knowledge production, which is applied, problem-focused, trans-disciplinary, heterogeneous, hybrid, demand-driven, entrepreneurial, accountability-tested, embedded in networks. Because Mode 1 is and remains the dominant form, it is more easily understood and recognised.

One possibility relates to two knowledge modes – the first more academic, the second more applied and complex…

Mode 2 is strongly concerned with knowledge that is useful – to a government or to some kind of user – and does not get produced at all until various groups negotiate its generation from different types of knowledge. Mode 2 knowledge is not created and then applied: it evolves within the context of its application, but then may not fit neatly into Mode 1 knowledge structures. The team generating the knowledge may consist of people of very different backgrounds working together temporarily to solve a problem. The number of sites where such knowledge can be generated is greatly increased; they are linked by functioning networks of communication. The knowledge is then diffused most readily when those who participated in its original production move to new situations and is communicated through informal channels. Quality control is more broadly based than in Mode 1. Individual creativity is the driving force of Mode 1 knowledge; in Mode 2, creativity is based in the group, which may nevertheless contain members socialised in Mode 1 forms.

… Mode 2 knowledge is created and diffused in very different ways than Mode 1…

It seems possible that knowledge production and use in the health and education sectors will follow science and technology towards Mode 2, at least in part. If this is so, then the changes in the high-tech industries must be examined

… and could start to characterise the health and education sectors.

Table 2. **Selected differences between the sectors**

Dimension	High tech	Medicine	Education
1. Pressures on knowledge creation, mediation and use			
Main source of pressure for knowledge creation	Market R&D	Clients R&D	Politicians
Pressure to innovation from own professional culture	Very high	Medium	Low
Priority given to knowledge creation and mediation	Very high	Medium	Low
2. Structures and resources for knowledge creation, mediation and use			
R&D expenditure	Very high	High	Low
Awareness of knowledge management ideas	High	Low	Very low
Application of knowledge management ideas	High	Low	Low
Actor networks	High	Medium	Low
Cross-specialism collaboration	High	Variable	Low
Expert-novice interactions			
Apprenticeship training mode)	Very high	Mainly high	Mainly low
Overall internal networking	High	Low	Very low
External organisational networks	High	Low	Very low
External actor networking	High	Medium	Low
Overall external networking	High	Medium	Low
Public-private collaborations	Strong	Weak	Very weak
Links with universities	Strong	Medium	Weak
Use of ICT in mediation	High	Medium	Weak
Mediation of new knowledge	Very fast	Fast	Slow
Implementation of new knowledge	Rapid	Variable	Slow
3. Outcomes of knowledge creation, mediation and use			
Level of success in knowledge creation	Very high	High	Low
Quality of R&D	High	Variable	Low
Rate of innovation	High	Variable	Low

very closely for possible lessons, the subject of the next chapter, before which an overview summary of similarities and differences between the three sectors is now provided.

Knowledge processes: a summary comparison across the sectors

Despite commonalties, the knowledge context differs across sectors:

The sectoral analysis reveals both commonalties and differences between the health, education and engineering sectors. Selected differences are listed in Table 2 (in which engineering focuses on high technology, medicine excludes pharmaceuticals and education refers mainly to schools). The sources and strengths of pressures to create and disseminate new knowledge vary sharply between sectors.

… health and education are driven less than engineering by market pressure or by resulting knowledge-creating professional cultures…

Engineering is under the greatest pressure towards knowledge creation and application, largely because survival depends on commercial success. Health and education are under increasing pressure from politicians and clients, especially in education, where lay people claim greater understanding of what is needed to improve the services provided. The internal professional pressure for, and priority given to, knowledge production and use is more variable among health and educational professionals than among engineers, where knowledge creation is part of the culture of firms that succeed.

R&D expenditure is highest among the technologists and lowest in education. Networks between actors within and across organisations, as well as between organisations, are widespread among high-tech firms, but much less so among health and education professionals, and where they exist they are likely to be within specialists. Apprenticeship modes of training – which socialise professional staff into internal networking – are weakest in education and strongest in engineering. The same rank order applies to an important form of external networking, links with universities. Inevitably the consequence is fast mediation and application of new knowledge in high-tech firms, but both are particularly slow in education. The rate, quality and success in knowledge creation, mediation and use is highest in engineering and lowest in education. These contrasts will be drawn upon and further developed in the next chapter.

… while high-tech industries outperform education in research, networking, university links and apprenticeships, so new knowledge is applied faster.

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Chapter 3

LESSONS FOR EDUCATION: CREATING A LEARNING SYSTEM

Introduction

We may project how education might adapt to the new knowledge economy, with reference to the above descriptions of how other sectors have done so…

Does education serve new roles in the knowledge economy? What adaptations will be needed in the knowledge-base and practices of professionals in the education service? How well are they adapting to the knowledge society and to what extent are they successful in preparing students for life and work in the knowledge economy? To help in these tasks, what should and could be done to improve the production, mediation and application of knowledge in education systems? In the previous chapter, some insights into these issues have been gleaned from the comparison with the other sectors, a process which has highlighted some of the strengths and weaknesses in existing education systems for producing, mediating and using knowledge. Education systems may well change, perhaps in some fundamental ways, in the near future and for a variety of reasons and causes: the knowledge economy will be one of the major drivers of these changes.

… and by noting that such an economy needs well educated lifelong learners, which can influence the education agenda…

Job creation is likely to be concentrated in knowledge-intensive industries, and more industries will become more knowledge-intensive, a trend which will accelerate the demand for highly skilled and well educated workers. In the knowledge economy, lifelong education for all puts huge pressures on the education service, from early childhood to adult education services. Extensive schooling reforms have been launched in many OECD countries, where there has also been an expansion of tertiary education. It is unclear to what extent these have been guided by a philosophy or explicit strategy for the kind of lifelong learning for all that is needed in knowledge economies.

… whose present features include:

The educational agenda has some common features across countries, including the following:

– broadening learning beyond schools and colleges,

– Lifelong learning involves people learning in a variety of places – leisure, work, home – not just formal educational organisations, which requires a fundamental shift in how people define education, take personal control over it, and shape it to their own goals and lives.

– "learning to learn", which implies radically new learning methods,

– Learning how to learn, and developing the meta-cognitive skills or meta-competencies to do so, become an important outcome for educational institutions, and especially for schools. All employees need the capacity to learn autonomously in a variety of settings and to contribute positively to their workplace as a learning organisation. However, it is unlikely that these skills and capacities can be taught through a didactic mode by professional teachers. Rather they need to be *modelled*. This means that students acquire such learning in an apprenticeship mode, with the professional teachers serving as "masters", but in a radically new version of apprenticeship in which the masters' skills are not traditional ones inherited from the past, but newly acquired highly transferable skills on themes such as learning how to learn and the art and craft of networking.

– easier access to the learning needed for constant adaptation to change at work,

– The shape of work and patterns of employment are changing (*e.g.* Brown, 1997; OECD, 1997). As people change jobs more frequently than in the past and as the life of particular skills gets shorter and shorter, education and training is needed in the workplace to complement formal educational provision. The demand for new forms of inexpensive, readily accessible education and training may change the function and structure of traditional institutions called schools and universities.

– better guidance and counselling,

– In the light of the above, more sophisticated systems of counselling and guidance are needed to ensure a good fit between people and their work, and for the right education and training for work. At present, member countries adopt different models for such services (Rees and Bartlett, 1999), which are relatively under-developed for the demands that knowledge economies will place on them.

– a more productive engagement in* ICT *as a knowledge mediator,

– The emerging global information society creates new "knowledge mediators", including the information and communication technologies (ICT), which supply supplementary services to the formal education system, either as a complement, when ICT supports student study at home, or as competition, home schooling, for example. Young people need IT skills, though many teachers remain technophobic. In many spheres of ICT, teachers have more to learn from students than to teach them. Developments in multimedia and in the software market have enormous implications for education, which are only now unfolding (OECD, 1998*c* and 1999).

– an expanding private sector, supported by* ICT, *especially in higher education, where quality issues are raised,

– In consequence of the above developments, there will be an expansion of educational services, especially ICT-based, from the private sector, operating in new forms of competition and collaboration with the public sector education services. This will be particularly marked in higher education, in response to the recent rapid growth of student numbers in North America, Europe and Australia, which are also responding to the considerable demand for student places from countries such as China, India, Mexico, South Korea, Taiwan and several countries in the Middle East. In particular, ICT and digital broadcasting are stimulating partnerships between universities and ICT companies for distance learning in globalised markets. Both France – with its new agency Edufrance – and Germany are also responding to these opportunities and the possibility that these markets could be dominated by the English language. The demand for high quality but inexpensive higher education seems likely to have a profound impact on universities over the next decade, as the very definition of higher education becomes uncertain (see Kogan in Part II).

– reform of tertiary education, partly to make it more responsive,

– Tertiary institutions are under pressure to become less dependent on government funding. Consequently, they have begun to seek new links with a broader range of "clients". Traditionally, the main purpose of tertiary institutions was the advancement and diffusion of knowledge through education and research in various disciplines. This is still the main purpose of the bulk of tertiary institutions, but governments are seeking, partly through budget cuts and financial initiatives, to make them more responsive to "the market" and to place greater emphasis on immediately useful or applicable knowledge.

– Expanded tertiary education necessarily has to clarify how it is to meet the changing needs of diversified clients, such as the balance between undergraduate and postgraduate students, between vocational and liberal courses, between the traditional disciplines and multi-disciplinary study and research, between research and teaching, and between international reputation and regional support. The nature of the partnership between universities and business and industry is of crucial importance to the success of knowledge economies (see Hans Schuetze in Part II).

– and to meet new clients' needs,

– At the same time, the boundaries between living and learning, between formal and informal education (Bentley, 1998), between vocational preparation and leisure pursuits, between school and community, all become more blurred. Partnerships between educational institutions and the home and the workplace will be need to be developed and sustained. Schools may evolve into multi-purpose, multi-age neighbourhood learning centres with easier access and longer opening hours, since the integration of households into learning networks may be the linchpin of a flexible, knowledge-based system of work (OECD, 1997).

– better integration of schools and communities,

– Though there will continue to be a concentration on the early acquisition of the basic skills of literacy and numeracy, schools are more and more expected to engage in moral and citizenship education, accepting the duties and responsibilities as well as rights of adult life, as a means of establishing social order and social cohesion.

– more systematic teaching of social values,

– In the learning economy, some knowledge becomes obsolescent very quickly. Individuals and institutions need to learn how to decide which knowledge should be forgotten and which needs to be remembered and stored.

– and the capacity to discard obsolete knowledge.

The rapidly rising expectations of parents and politicians about what students should achieve and what educational organisations should do to guarantee these achievements are putting teachers under heavy pressure to find much more effective ways of teaching and of managing educational organisations. Teachers cannot do this by working harder, but by working smarter, which means achieving higher productivity through knowledge creation and application, which in turn is likely to mean re-conceptualising the nature of educational organisations and re-structuring and re-culturing them accordingly.

Rising demands on teachers can only be met by smarter use of knowledge in changed organisational cultures.

This chapter poses five questions, arising out of CERI's current work and the present study, and suggests some possible responses to them.

Five questions for education are raised in this chapter…

– What knowledge (and innovation) is likely to be needed and by whom in education systems of the future?

– What are the best ways of *i)* producing, *ii)* mediating/disseminating and *iii)* applying such knowledge?

– What action needs to be taken to increase the education system's capacity for the successful production, mediation and application of knowledge, and what infrastructure might be needed to support and sustain this capacity?

– How can this be done to ensure that education systems are efficient and effective and meet the new goals and functions that are likely to be set for them?

– In particular, how might all these developments influence and support "schooling for tomorrow"?

... which can be answered in a framework of managing knowledge rather than producing, transmitting and applying it sequentially.

A framework for responses to these questions can be derived from the earlier analysis, and these are the sections of this chapter. To avoid any implications of linearity and for simplicity, the processes involved in "the production, mediation and use of knowledge" will be brought together in the overarching term, *knowledge management*. Within an organisation, such as a commercial company, a hospital or a school, knowledge management can be understood as the management of its intellectual capital, as knowledge is a form of capital that, like physical or financial capital, has be managed to achieve the aims of the organisation. This chapter responds to the questions from the emerging perspective of knowledge management, through the following eight themes:

- Developing a commitment to knowledge management.
- Expanding the role of practitioners in knowledge management.
- Establishing and using networks for knowledge management.
- Using ICT to support knowledge management.
- Forging new roles and relationships between researchers and practitioners to support better educational R&D.
- Devising new forms of professional development for practitioners that reflect and support knowledge management priorities.
- Integrating knowledge capital and social capital.
- Designing an infrastructure to support knowledge management.

Each theme incorporates the questions set out above and is now examined in turn.

Developing a commitment to knowledge management

Knowledge management has been recognised by industry but barely so far in health and education...

In industry, and especially fields that are knowledge-intensive, such as electronics, biotechnology and pharmaceuticals, the concept of knowledge management is just over ten years old. During the 1990s, the literature has grown rapidly (Chapter 2), with books, academic journals and professional magazines devoted to the topic. Indeed, so many firms now have a Chief Knowledge Officer that surveys of the role have been undertaken (Guns, 1998; Earl and Scott, 1999) and its existence is acknowledged in government publications (*e.g.* UK Department for Trade and Industry, 1998). In the health and education sectors, by contrast, the concept has, with few exceptions (Rowland, 1998; Hargreaves, 1998 and 1999), as yet made little if any impact, despite the fact that these can also be considered knowledge-intensive fields.

... teachers are largely oblivious of how they could manage knowledge better...

The principal function of educational institutions is the transmission or cultivation of knowledge, skill and understanding in students, but the creation and management of the professional knowledge of the staff, which could potentially enrich and improve teaching and learning, is largely ignored. Moreover there is a widespread reluctance among educationists to believe that there is much that they might learn from business and industry, and perhaps especially from engineering, to help them in their work.

... and have codified or shared little of their largely personalised knowledge base...

It is evident from the previous chapter and from studies of the teachers' knowledge-base (OECD, 1996; Hargreaves in Part II) that teachers possess relatively little in terms of a common body of codified, explicit knowledge to underpin their work – an equivalent to mathematics and physics for the engineer, or the biological sciences for the doctor – and they tend to work in a very individualised setting, one teacher with a group of students in a classroom, in which they acquire much of their professional knowledge by trial-and-error, on-the-job learning. Teachers' professional knowledge is thus personal rather than collective, and more tacit than explicit. Teachers in a typical secondary school have on average between ten and twenty-five years teaching experience, which amounts to the equivalent of several centuries of experience. Very little of this knowledge is shared or collective knowledge: it is mostly locked in the heads of individual teachers.

… a first step is to uncover this existing base of what teachers know…

In several OECD countries, schools are developing systems of self-evaluation or review (MacBeath, 1999), in which an audit of selected aspects of the school, such as the curriculum or resources, is undertaken. Perhaps the first step towards knowledge management in school would be an audit of the professional knowledge of the staff to uncover and map *what* they know about teaching and learning, and *who* knows what. The audit would also uncover what the teachers do not know, and perhaps need to know. There is considerable guidance available from the business and industry about the conduct of such an audit and the subsequent mapping of, and creation of repositories for, the outcomes (McGee and Prusak, 1993; Bohn, 1994; Skyrme and Amidon, 1997; Davenport, DeLong and Beers, 1998; Ward, 1998).

… so institutions could start to manage knowledge by sharing it internally.

By investigating its own collective knowledge and ignorance a school or a university should come to realise the potential strength of collective, shared knowledge; the extent and importance of tacit knowledge and the difficulties of rendering it explicit; the gaps in current knowledge and the possibilities of reducing collective ignorance. "When we know what we know and know what we do not know, we know what we need to know and what we might need to do to create and share such knowledge." In short, an audit of knowledge might, as in industry, be an incentive to manage it more effectively and to create knowledge to meet the challenges of schooling for tomorrow.

Expanding the role of practitioners in knowledge management

Teachers, like other professionals, are knowledge producers, constantly conducting informal classroom experiments…

Teachers are engaged in the production of knowledge, but they do not usually think of themselves in this way. Teachers, like all professionals, face problems and seek to find solutions to them. Doctors learn to *tinker* in their work.

> The [medical] practitioner is a fairly crude pragmatist. He is prone to rely on apparent "results" rather than on theory and he is prone to *tinker* if he does not seem to be getting results by conventional means [and] the clinician is prone in time to trust his own accumulation of personal, first-hand experience in preference to abstract principles or "book knowledge" particularly in assessing and managing those aspects of his work that cannot be treated routinely (Freidson, 1972, italics added).

So do engineers.

> [E]fforts at innovation almost always involve a large element of trial and error and try-again learning (…). R&D continues to be an activity in which dead ends are often reached, and a lot of trying, testing, and revising is required before a successful result is achieved (…) [by a] process of cumulative improvement and variegation (…). The lines between R&D and other activities, such as designing products for particular customers, problem solving on production processes, or monitoring a competitor's new products, are inherently blurry (Nelson, 1993).

The teacher does much the same.

> Essentially teachers are artisans working primarily alone, with a variety of new and cobbled together materials, in a personally designed work environment. They gradually develop a repertoire of instructional skills and strategies, corresponding to a progressively denser, more differentiated and well integrated set of mental schemata; they come to read the instructional situation better and faster, and to respond with a greater variety of tools. They develop this repertoire through a somewhat haphazard process of trial and error, usually when one or other segment of the repertoire does not work repeatedly (…). When things go well, when the routines work smoothly (…) there is a rush of craft pride (…). When things do not go well (…) cycles of experimentation (…) are intensified (…). Teachers spontaneously go about *tinkering* with their classrooms (Huberman, 1992, italics added).

> Teaching, if it is to be done effectively, involves experimentation. This is inherent in the nature of the activity. Some children learn rapidly, others slowly; what is effective for one may not be effective for another. From time immemorial teachers have had to find out for themselves what works with which children and with which subject matter. There always have been teachers who have been particularly reflective about general principles and about particular techniques, and who have, as it were, systematically experimented (Murnane and Nelson, 1984).

Tinkering is an important component in the practice of all professions and a form of learning and of knowledge creation among scientists (*cf.* Knorr, 1979).

… this tinkering serves first to test if something works…

Tinkering serves several functions. First of all, it is a source of knowledge creation, because when something does not work in practice, tinkering is a kind of experiment to discover something that *does* work.

> When the phenomenon at hand eludes the ordinary categories of knowledge-in-practice, presenting itself as unique or unstable, the practitioner may surface and criticise his initial understanding of the phenomenon, construct a new description of it, and test the new description of it by an on-the-spot experiment (Schön, 1983).

… second, to adapt abstract knowledge to one's own circumstances…

Furthermore, if the knowledge is new, some learning is required to transform it from an abstract, decontextualized idea into something one can use in one's own practice, and/or its application has to be modified to fit local circumstances. Implementing new knowledge is necessarily a small-scale version of R&D. In professional work, the task of application, with the necessary fine-tuning and adjustment, simultaneously involves an act of knowledge creation (Rosenberg, 1982).

… third to integrate with one's previous knowledge…

Moreover, the new knowledge has to be *integrated* with the rest of one's knowledge relevant to this practice, and this process of integration can be slow and difficult, in part because the new knowledge is likely to be explicit – something one has read about, been told about or observed – whereas to be usable the new knowledge has to be integrated with pre-existing tacit knowledge. Indeed, the act of tinkering may be the way in which one acquires the tacit element that is inherent in the new knowledge.

… and last as a means of sharing knowledge with other practitioners.

Lastly, tinkering is often easier if it is done with another person or group. If two or more tinker together, they can share ideas, support one another and combine application with the creative elements that are part of the modifications made through tinkering. As we have seen, teachers tend to work alone in their classrooms. Though team work among teachers has increased in recent years, it is by no means a common or normal way of working. Novice teachers often feel the need to hide their problems, on the grounds that to expose them is to display one's incompetence. Mutual tinkering is one route to enabling teachers to explore professional learning through mistakes and failures, which are inherent in tinkering. Most schools have much to learn from knowledge-intensive firms where learning through failure is part of the culture of success.

> Failure was viewed as an opportunity for learning (…). These entrepreneurs learned both from their own experiences and from those of their colleagues and predecessors. George Gilder describes how this phenomenon of succeeding by learning from failure enhanced the region's competitiveness: "Unless failure is possible, no learning is possible (…) and so the tolerance of failure is absolutely critical to the success of Silicon Valley. If you don't tolerate failure, you can't permit success. The successful people have a lot more failures than the failures do" (Saxenian, 1994).

A more integrated model of knowledge process gives practitioners a greater role in production.

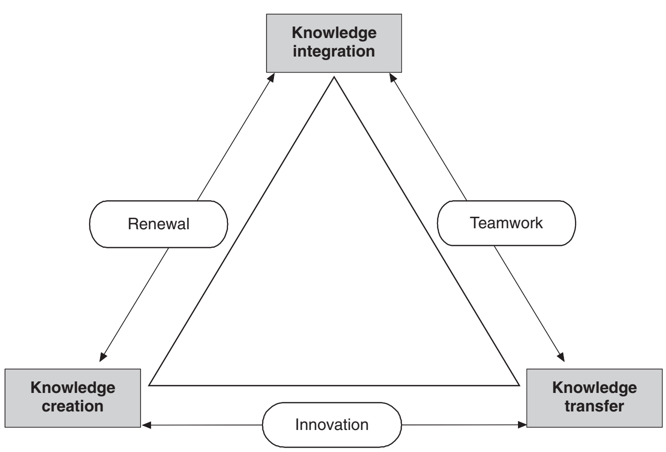
It is clear that even interactive models of production, mediation and use can be represented in too simple a form, as in Figure 2 in Chapter 2. In the more sophisticated model in Figure 3, taken from Fruin (1997), innovation is explicitly in a knowledge production Mode 2 form. The application of knowledge requires that it be integrated, and integration is linked to both knowledge creation and knowledge transfer.

The improvement or renewal of practice links creation and integration. In other words, practitioners in education could, as in medicine and engineering, play a much more active role in knowledge creation.

Helping students to learn how to learn is a complex process…

The concept of life-long learning means that students must "learn how to learn" – and do so at school before entering further or higher education. The authority of the teacher has hitherto rested primarily in expertise in a subject of the curriculum and in the skill of teaching it. Teachers, especially at school level, now need to teach students to "learn how to learn", a highly complex idea embracing several elements:

Figure 3. **Mode 2 – Knowledge creation, transfer and integration**



– Being motivated to learn throughout life.

– Being skilled at identifying one's own learning needs or knowing how to get help with this task.

– Being able to identify the kind of education and training to meet those needs and how it is to be accessed.

– Being able to acquire a range of meta-cognitive skills – thinking about one's own thinking, learning how to be flexible with learning styles and strategies.

– Being able to learn independently and in a range of contexts (work, leisure, home) other than formal educational organisations.

– Learning how to access information and knowledge from the new world of the information and communication technologies.

… which requires a pedagogical transformation that has to be driven by collaborative professional effort rather than by pure research.

All this requires the production and application of new pedagogic knowledge on a huge scale, and it is difficult to see how that can be done without the active engagement of practitioner-teachers in schools. Creating a much larger educational research community to undertake this task is unlikely to work, since this type of model in industry has been discredited (Camagni, 1988). Part of the explanation is the problem of transfer inherent in linear models of this type. Researchers work largely through explicit and codified knowledge. Teachers rely on high levels of tacit knowledge. Researchers do not share the tacit knowledge of teachers: they have their own tacit knowledge. One of the reasons for the low rates of successful application of research knowledge in education may stem from these deep problems of transfer, to which we now turn.

Establishing and using networks for knowledge management

The transformation of schools requires that teachers become more collaborative…

The creation and application of professional knowledge on the scale and in the time-frame demanded by "schooling for tomorrow" make demands at the individual and system levels. At the level of the individual teacher, there needs to be a psychological transition from working and learning alone, with a belief that knowledge production belongs to others, to a radically different self-conception which, in conformity with interactive models, sees the co-production of knowledge with colleagues as a natural part of a teacher's professional work. At the system level, ways have to be found to bring teachers together in such activity.

… not easy, given their numbers, but networking could be a key element…

The teaching force is large and diverse (OECD, 1998*a*). Taking just the primary schools, there are, as examples, 188 000 teachers in France, 170 000 in Germany, 21 000 in Ireland, 264 000 in Italy, and 80 000 in the Netherlands. Discovering how to create, disseminate and apply new professional knowledge is a huge challenge. Though conventional methods – written guidance and suggestions, courses of teacher education and training – will always play a role, they are too slow, costly and inefficient to meet the need. Teachers are aware of this, for they often complain that individual schools and individual teachers spend too much time "re-inventing the wheel". Could networking help to solve this problem? In the industrial sector, the study of networks has for some time been a well established field for academic study (Nohria and Eccles, 1992) and as was discussed in the last chapter, networking is a significant feature of the success of knowledge-intensive firms. Transforming teachers into a networked profession may prove to be an important means of improving the management of knowledge capital on which effective schooling for tomorrow rests. However, among teachers, in comparison with engineering professionals, networking is under-developed.

... by recognising existing networks, strengthening them and using them more systematically...

All schools are already network organisations in some sense, in that they contain internal networks among the staff and develop external networks with other individuals and organisations, including other schools. But teachers do not speak much of networks, perhaps because of the tendency to view the school as a *place* rather than as a network-of-interactions (Tsoukas, 1992). The task therefore is threefold: first, to find ways of making teachers more aware of their existing internal and external networks; secondly, to help them to recognise the potential value of strengthening those networks; and thirdly, to learn how teachers might deploy such networks in the interests of professional knowledge creation, dissemination and use.

... not only internal ones, but importantly with others outside.

A school's audit of its professional knowledge should include an audit of its networks, both internal and external, to ensure a collective appreciation of what these are, how they are currently being used and whether they could be used and developed to further advantage. Hitherto, many schemes of school development and improvement have focused on the individual school, which has strengthened internal networks, but not necessarily external ones. It is the extension of networking beyond the single school which may be important for better knowledge management, for this seems to be the case with knowledge-intensive biotechnology companies, which create alliances among themselves and with universities.

> In industries where the relevant know-how is broadly dispersed, innovation depends on co-operative interaction among different types of organisations. The locus of innovation becomes a network rather than an individual firm. We anticipate that firms with more internal knowledge are more willing to pursue a strategy based on alliances and agreements (...). [N]etworks are particularly well suited for rapid learning and the flexible deployment of resources (...). [B]iotechnology may represent a new kind of industrial order – one in which production depends heavily on the exchange of knowledge and the most critical skill is to develop internal expertise and simultaneously maintain ongoing collaborations with external sources of knowledge and expertise (Powell and Brantley, 1992).

Transferring knowledge from one teacher to another requires the latter not just to receive information but to transform and apply it in her own situation...

Like all other professionals, teachers gossip, share stories and experiences both good and bad, talk over ideas: these are internal networks in which professional know-how is traded (von Hippel, 1987). But this does not go far enough. The transfer of practical knowledge between professionals involves more than *telling* or simply providing *information*. If one teacher tells another about a practice that the first finds effective, the second teacher has merely acquired information, not personal knowledge. Transfer occurs only when the knowledge of the first teacher becomes information for the second, who then works on that information in such a way that it becomes part of his or her context of meaning and purpose, is integrated into pre-existing knowledge and is then applied in action. Transfer is the conversion of information about another person's practice into one's personal know-how: it is a complex piece of interpersonal engineering or transplantation. This explains why so much dissemination fails, for dissemination makes the information more widely available, but does not provide the support which allows the receiver of the information to convert it into personal knowledge that can be successfully applied. Conversion of *abstract information* into *applicable know-how* is the very essence of transfer and it is most easily achieved when a teacher tinkers with new knowledge and tests it and, where necessary, modifies it to fit a different context and, on finding that it works, adopts it. It is when two or more teachers tinker together that the transfer of knowledge between them is most likely to succeed.

... and such mutual tinkering is not automatic in teacher networks; it needs active encouragement.

Following pioneering studies in the 1980s (Little, 1982; Rosenholtz, 1989), collaboration among teachers has been seen as a vital element in school improvement and is a means of strengthening internal networking. But collaboration may be restricted to teachers working alongside one another: it does not automatically mean mutual tinkering, nor does it necessarily entail the creation of knowledge or its transfer between teachers.

> The most acceptable and useful form of knowledge transfer is interpersonal in that it is economical and easy to access, permits two-way interactions and allows for the numerous indirect probes by which practitioners test the credibility of one another's accounts and the pertinence of incoming data to their own practice (Huberman, 1983).

Collaboration creates conditions that support mutual tinkering, but the tinkering needs to be actively encouraged rather than assumed.

More difficult is the transposition of knowledge from one school's context to another's...

The dissemination of professional knowledge from one person to another is *knowledge transfer*. In a second form, the knowledge is disseminated from one *place* (a classroom, a school) to another: this is *knowledge transposition*. Internal transfer, though teacher networks in the same school, is in most cases easier to achieve than external transfer, or that between teachers in different schools. The conditions and circumstances, such as the character of the student intake and the organisational culture, are relatively constant within a school; and it is easier for two teachers to meet and tinker together. Disseminating knowledge from one school to another involves both transfer and transposition, and there may be marked differences in the character of the schools, the background of the students, the values of the teachers and so on. What works in one school may not work in another school because of these differences in context. Moreover it is more difficult for two teachers in different schools to find opportunities to tinker together, which is so helpful to successful transfer.

... and hardest is transposition across secondary schools (or even within secondary schools) because of specialised knowledge bases among subject teachers.

In matters of transfer and transposition, there are significant differences between primary and secondary schools. In primary schools, the teachers are mainly non-specialists, and so interchangeable, sharing a common knowledge-base and professional language, and similar experiences since they teach a common curriculum to children of about the same age. Transfer of knowledge and integration into the knowledge-base are thus much easier than in the case of secondary teachers, who are usually specialists by curriculum subject(s) with differentiated knowledge-bases and professional language and therefore differing content in much (but not all) of their tacit knowledge. Indeed, transposition among secondary teachers of the same subject but in different schools may be easier than transfer between teachers of different subjects in the same school. Internal networks in secondary schools may span subject boundaries only rarely and under particular conditions. Secondary schools principals may have to encourage "boundary spanning" between subject specialisms to provide the conditions for "creative abrasion" (Leonard-Barton, 1996), the process by which combining differences generates innovation. Principals of primary schools are essentially like all other primary teachers, since they come from the same stock of experience. By contrast, the principals of secondary schools come from just one or two of the many subject specialisms represented in the school and so lack the tacit as well as the subject knowledge of many of the teachers. They are likely to be managers, rather than practising teachers, especially in some countries such as Belgium and Italy (OECD, 1998*a*). Persuading teachers of different subjects to engage in mutual tinkering, in the belief that they can learn from and with one another in spite of their differences, is a challenging task for secondary principals.

The difficulty encountered in transferring knowledge, described as its "stickiness", needs to be understood and addressed by those seeking change...

Although networking is one of the keys to successful schooling for tomorrow, the process of making new knowledge about effective teaching and learning both transferable and transposable is not as yet well understood. It cannot be assumed that knowledge passes through some channel of communication from sender to receiver in a friction-free way. In this regard von Hippel's (1994) concept of "sticky information" is an aid to identifying the problems. "Stickiness" refers to the cost – effort, resources – involved in transferring information or knowledge from a provider (or source) to a seeker (or recipient). Stickiness is directly proportional to the cost of transfer or transposition. It may be a feature of the knowledge itself – tacit knowledge is much stickier than explicit knowledge – but it may also lie in the provider (*e.g.* who may not be seen as a credible source of new knowledge), or in the recipient (*e.g.* who lacks motivation to receive it), or in the transfer process (*e.g.* a lack of incentive to provide or receive). In this way, the concept of stickiness can be used as the basis for defining and explaining those situations in which transfer and transposition are most and least likely to be successful. Providers of new knowledge for teachers, whether they be administrators, politicians or academic, rarely think of the stickiness involved in their communications about new knowledge or "good practice" and the preventive action they might take to make it less sticky.

... who should note that the ability rather than the willingness to apply outside knowledge may be the problem.

There is no direct evidence on the stickiness of new knowledge in education, but the results of a study in industry of 122 transfers of 38 practices in 60 companies by Szulanski (1996) indicated that in this sector the most important origins of stickiness are not those of the conventional wisdom, which attributes stickiness to lack of motivation and resistance of the "not invented here" type among recipients. Rather, the three top factors were:

– A lack of "absorptive capacity" (see Chapter 2) in the recipient, that is, lack of an appropriate stock of pre-existing knowledge suitable for the assimilation of the new knowledge.

– Ambiguity about the factors that cause the good practice to "work".

– Difficulty of communication between the provider of the good practice and the recipient.

As Szulanski suggests, unsuccessful transfer may occur "less because organisations do not want to learn but rather because they do not know how too". Were these findings to apply to educational organisations, there are profound lessons for school improvers and reformers.

Using ICT to support knowledge management

ICT is a useful tool, but networking will spread only if given high priority...

All schools can now be linked through ICT and so *all* can take part in the activities of professional knowledge creation, application and dissemination. In industries where the knowledge is both complex and expanding and the sources of expertise are widely dispersed – as is becoming the case in education – the locus of innovation is to be found in networks of learning. Developing networks among schools is difficult to achieve, even at the local level, since most of the teacher's day is already allocated to classroom teaching. If it were clear that networking is worth the effort, more could be done to network. For example, in some countries schools are allowed to close for a day from time to time for a professional training day for the staff in the absence of students. Such days are usually spent in staff activities in the school, but they could be used for network visits to other schools.

... for which there is a case, given evidence on its value in the electronics and biotech sectors.

The evidence on the value of inter-firm networking on successful innovation and knowledge transfer is generally positive (Lundgren, 1995; Coombs, *et al.*, 1996), and specifically in electronics and biotechnology firms (*e.g.* Kenney and Florida, 1994). Innovating biotechnology companies

> (...) are executing nearly every step in the production process, from discovery to distribution, through some form of external collaboration. These various types of inter-firm alliance take on many forms (...). The R&D intensity or level of technological sophistication of industries is positively correlated with the intensity and number of alliances (...). Knowledge creation occurs in the context of a community (...). To stay current in a rapidly moving field requires that an organisation has a hand in the research process. Passive recipients of new knowledge are less likely to appreciate its value or to be able to respond rapidly. In industries in which know-how is critical, companies must be expert at both in-house research and co-operative research with such external partners as university scientists (...). A firm's value and ability as a collaborator is related to its internal assets, but at the same time collaboration further develops and strengthens those internal competencies (...). When the locus of innovation is found in an inter-organisational network, access to that network proves critical. R&D alliances are the admission ticket, the foundation for more diverse types of collaboration and the pivot around which firms become more centrally connected (...). As a result of this reciprocal learning, both *firm-level* and *industry-level* practices are evolving (...) (Powell, Koput and Smith-Doerr, 1996, italics added).

The pedagogical value of ICT should not mask its potential, proven in other sectors, for helping develop professional knowledge networks...

The growth of ICT in schools is mainly seen as a source of ready access for teachers and pupils to materials that can be used for the purposes of teaching and learning. Important as this is, it can overshadow other important purposes. Linking every school to ICT networks, which is occurring in some countries, is facilitating the formation of inter-school and inter-teacher networks of many kinds and in various forms, such as data-bases of good practice and virtual teachers' centres and forums for debate and discussion. A model of what could be done already exists in industry. In his analysis of the impact of IT on industrial networking, Freeman (1991) reported a strong upsurge of research collaboration and networking since the 1960s and a significant qualitative change in the nature of earlier forms of collaboration and networking. He writes that ICT:

> (...) provides entirely new possibilities for rapid interchange of information, data, drawings, advice, specifications and so on between geographically dispersed sites (...) it provides the technical means for improving communication networks everywhere and for making them feasible in areas where they could hardly have been introduced before. It is a networking technology *par excellence* (...). IT not only greatly facilitates various forms of networking, but has inherent characteristics such as rapid changes in design, customisation, flexibility and so forth, which, taken with its systemic nature and the variety and complexity of applications, will lead to a permanent shift of industrial structure and behaviour. This will assign to networking a greatly enhanced role in the future.

Schools (and hospitals) are catching up with high-tech firms; and teachers are catching up with doctors, who have still to catch up with technologists. The nature of institutions and the roles of teachers will be profoundly affected by these changes. ICT has a huge but as yet uncertain potential to promote professional knowledge creation and dissemination among teachers, but there are limits that must be recognised.

... which higher education is already starting to exploit...

Related changes are likely to be experienced in the near future in higher education. Partnerships between the leading US universities, such as Berkeley, Columbia and Michigan and companies which could supply the technology for distance learning materials, such as Disney Corporation and Microsoft, will generate inter-institutional networks of changed roles within a new distribution of labour. In response to the imperatives of economic globalisation, traditional non-profit research universities seek to become major players in the emerging for-profit market of continuing education for adult learners of the Internet. We are already seeing a new form of university institutions that exist only in the cyberspace such as Western Governors University or Jones International University. The mid-career development of professions such as engineers will require novel combination of ICT, distance learning and residential courses (Ferguson, 1998).

... but collaboration cannot all be done at a distance, since little knowledge is perfectly explicit...

These new media allow the sharing of explicit knowledge in the form of ideas and experiences, designs and documents, but these can easily become de-contextualized and thus difficult to transfer/transpose and replicate (Tyre and von Hippel, 1997), especially where there is considerable tacit knowledge involved, which really requires people to meet and tinker to achieve transfer. In Silicon Valley, proximity of the firms facilitated the face-to-face communications needed for successful collaborations, particularly the continuous engineering adjustments or "tinkerings" required in making complex electronic products. As one executive reported to Saxenian (1994):

> An engineering team simply cannot work with another engineering team that is three thousand miles away, *unless the task is incredibly explicit and well-defined – which they rarely are*. If you're not tripping over the guy, you're not working with him, or not working on the level that you optimally could if you co-located (italics added).

The implications of this for regional consortia of educational institutions and private sector firms, and the potential contribution of such local consortia to the success of larger, international partnerships in the globalised higher education markets, are at this stage simply a matter for speculation and hypothesis.

... so schools need to give staff time to collaborate and tinker through personal contact.

Here is a role for school principals in supporting internal and external networks for their staff. With regard to some of the central aspects of knowledge creation, transfer and application there is simply no substitute for peers talking and tinkering in face-to-face interactions. This is expensive of professional time and often difficult to manage, so there is always a danger that school leaders will seek to introduce mediators and managers, or well-intentioned formal courses, to simplify this task. It is commonplace for secondary teachers to be allowed some time during the school day for preparation or marking or professional development: the same priority now needs to be given to opportunity for tinkering towards knowledge creation. In most countries educational organisations, especially at secondary school level and above, remain very hierarchical, where the inclination to manage innovation from above through top-down direction is most acute – and most dangerous. The warning from industry is clear.

> Once firms are viewed as institutions for integrating knowledge, a major part of which is tacit and can be exercised only by those who possess it, then hierarchical co-ordination fails (...). When managers know only a fraction of what their subordinates know and tacit knowledge cannot be transferred upwards, then co-ordination by hierarchy is inefficient (...). Only one of the integration mechanisms (...) is compatible with hierarchy: integration through rules and directives (...). The recent vogue for team-based structures where team membership is fluid, depending on the knowledge requirements of the task at hand, is one response to the deficiencies of hierarchy. The essence of a team-based organisation is recognition that co-ordination is best achieved through the direct involvement of individual specialists and that specialist co-ordinators ("managers") cannot effectively co-ordinate if they cannot access the requisite specialist knowledge (Grant, 1996).

Forging new roles and relationships between researchers and practitioners to support better educational R&D

Like other fields, education research is under pressure to become more applied...

The expansion of student numbers in higher education in many countries, sometimes associated with reduced funding per student, puts a strain on the commitment of universities to research. The character of the research may also be affected by the growing influence of user communities, who are inclined to favour short-term, applied research rather than curiosity-driven, "blue skies" research of a more basic kind. These same influences are at work in the field of education.

... and cannot rely on theoretical breakthroughs to change the paradigm; routine improvements of professional knowledge are more fruitful...

Some R&D will continue to be strongly led by universities, especially in fields where basic research relevant to education is conducted. In recent years many in education have become excited by the potential applications in education of advances in cognitive science, evolutionary psychology and neuroscience, especially through recent popular writing by William Calvin (1996), Steven Pinker (1997), Henry Plotkin (1997) and Susan Greenfield (1997). It seems very unlikely that there will be any short-term educational applications from current work in the neuro-sciences, though cognitive psychology may provide the essential bridge (Bruer, 1997), and even here there will be a need for mediators and brokers to bring this to classrooms. It is at this stage probably more sensible to assume that in education, as in many other fields, innovation is not a matter of "big ideas" or technological breakthroughs or absolute novelties, but rather should be directed to the routine exploitation of existing professional knowledge and teaching technologies. This directs the search for new knowledge to what happens currently in schools and to discovering systems by which the education system distributes professional knowledge so that it can be recombined into knowledge creation (Foray, 1994).

... with Silicon Valley an example of close user-researcher interactions...

In the success story of Silicon Valley, the close relationships between researchers and users have been of long standing. The record shows how a virtuous spiral of excellence was created through the mutual dependence of university and high-tech industry.

> The role of Stanford University, and specifically that of its visionary vice-president, Frederick Terman, was critical to the beginning of Silicon Valley. In 1920 Stanford was just a minor league, country-club school. By 1960 it had risen to the front ranks of academic excellence. The rise of Stanford implemented the take-off of the Silicon Valley microelectronics industry. And Silicon Valley helped put Stanford University where it is today (...). One of Terman's most direct influences on the rise of Silicon Valley was his

role in launching Hewlett-Packard (…). Terman learned that Hewlett and Packard planned to start their own electronics business after graduation and encouraged their entrepreneurial spirit (…). The Stanford Industrial Park, created in 1951, was the first of its kind. Terman called it "Stanford's secret weapon". Through land leasing, the purpose was simply to earn money for the University. Only later did the Park become a means of transferring technology from the university's research labs to firms in the park. In 1954 (…) Hewlett-Packard built their company headquarters on one of the choicest pieces of land on the campus (…). Terman used the tidy incomes from the Park to create a "fighting fund", designed to recruit and retain star faculty (…). Many of the early Palo Alto engineers were Stanford graduates and even though they might work for competing firms they remained close friends (Rogers and Larsen, 1984).

… and a wider range of industrial examples of non-linear knowledge development…

Though the symbiosis of university and industry in Silicon Valley may well have some unique features, the ability to circumvent the dangers inherent in the long chain of stages in the linear model of knowledge production and application has been acquired in many industrial contexts.

"*We don't have a separate* R&D *laboratory* (…) *the development work is done right here on the manufacturing floor* (…)". Innovation cannot be walled off as the responsibility of a small clearly defined group of formally designated innovators. Rather, innovation must pervade the firm, with roots and links in all key functional areas (…). Stage barriers – between research and development, between development and manufacturing – must be transcended and integrated (…). Overlap, contact and negotiation are the norms (…) (Jelinek and Schoonhoven, 1990).

Linking an R&D project to production as early as possible, instead of waiting for a technological breakthrough (…) has the advantage of enabling earlier market feedback through experimental commercialisation. Market needs are thus linked to the R&D process at an earlier stage, when changes can be made more easily (…). This incorporation [of scientific knowledge into the production process] depends not only on the transfer of researchers to development and production, but also on initial immigration of development and production engineers to inventional activities. Similarly, extracorporate professors, researchers and engineers may be interlinked (and sometimes imported) from the same sort of sources to the project (Harryson, 1998).

Orthodoxy holds that basic and applied research are highly specialised activities that necessarily occur upstream from actual process and production engineering. Accordingly, basic and applied research are best isolated from the daily hustle and bustle of operations management, product planning, and marketing. Most research labs, even applied ones, are far removed from the mundane world of everyday manufacturing and management. Toshiba stands this orthodoxy on its head (…). Toshiba concentrates 75% of its R&D personnel at the factory level of organisation and another 15% at the divisional or sectoral levels, thereby consolidating 90% of its R&D workers below the level of central R&D (…). As long as Toshiba is able to capture, consolidate and integrate most of the knowledge and know-how that flow from this design solution, it appears to shorten time-to-market speed and capitalise on learning opportunities up and down the value chain of applied research, design, development and manufacture of new products (Fruin, 1997).

The lessons that might be drawn from this have still to be learned in some university departments, in terms both of its own relationship to the world of professional practice and to the need for regular opportunities for the interchange of staff.

... demonstrating the permeability of the boundary between research and application, pertinent to teaching...

There is, then, no definite boundary between the production of knowledge and its application – the two are enmeshed in principle and practice as creation is fused with implementation. The problem has been noted in schools. Among teachers:

> (...) the recipes are traded on the basis of a validity that is craft embedded and highly experiential (...). Research evidence is an unlikely source of practitioner information, not only because it assumes an underlying order but also because the ways in which the theoretical or scientific sources talk and write about instrumental practice are uncongenial: the two frames of reference collide (Huberman, 1983).

... but not yet leading to a changed structure for applying educational R&D that emphasises "Mode 2" knowledge in a closer researcher-practitioner partnership...

Such insights have not so far led to a widespread, radical restructuring of educational R&D that brings researchers and teachers into a much tighter partnership, by which they engage in sustained dialogue to design, implement and evaluate R&D projects or researchers move into schools to work alongside teachers as R&D partners. In other words, the lesson has still be learned by many educational researchers that a movement towards Mode 2 knowledge production in education will require deep change in the ways educational R&D is conceptualised and implemented. Yet the potential pay-off of such a change for the improvement of formal education systems is enormous. Such a role for university-based, educational researchers entails:

- Training and supporting practising teachers in research skills, including knowledge validation, to enable them to carry out more school-based research for knowledge creation.
- Interpreting their partnership with teachers less often as occasions for transmitting academic or research knowledge to them and more often as opportunities to contribute to the integration and combination of different kinds of knowledge as an important ingredient of teacher-led knowledge creation.
- Co-ordinating dispersed, school-based R&D programmes, from small-scale, preliminary knowledge creation in a consortium of two or three schools to large-scale, multi-site experiments, in order to create bodies of cumulative knowledge about effective pedagogic practices.
- Helping to disseminate the outcomes through networks of schools and teachers.
- Making the study of the creation, dissemination and validation of knowledge in education a focus of university-led research.

... through which school-generated knowledge could enrich academic knowledge, not undermine it...

Such ventures undertaken by proactive universities might create for education the equivalent of science parks for technology. School-based, applied R&D would not replace basic research in universities and research institutes, whether these are focused on education or on relevant disciplines (psychology, sociology, economics), but would complement and enrich it. It has been demonstrated (Larédo and Mustar, 1996) that networks in France between universities, firms and users can successfully achieve technological innovation without damaging the need for academics to engage in "basic" research and publish in refereed journals: education could learn from this example.

Researchers in Schools of Education in universities must not restrict their new partnerships to teachers in schools, but extend them to two other types of partner, who have been relatively neglected – fellow-teachers in post-school educational institutions and those responsible for professional development in the world of work. There is a clear need for models of teaching and learning that are more appropriate for adults, who will need to study in modes that are atypical of traditional, academic learning based in schools and universities, namely part-time and distance learning, involving accreditation of prior learning and credit accumulation. Of particular importance here will be the need to develop and refine comprehensive models of integrated work and learning (Brown and Duguid, 1991; Engström and Middleton, 1996; Raelin, 1997), to underpin models of knowledge management and of innovation. This task will require cross-disciplinary and cross-institutional collaborations among educational researchers. Those with responsibility for education and training at work tend to exaggerate the importance of formal education and training and neglect the opportunities for informal, on-the-job education and training (Eraut *et al.*, 1998) and the need for work-based strategies to support and extend it. It is from such R&D partnerships that new and better modes of professional development should emerge.

... and the study of learning could draw not just on experience in schools, but in other educational and work organisations, not neglecting on-the-job learning.

Devising new forms of professional development for practitioners that reflect and support knowledge management priorities

The apprenticeship mode of learning for the novice professional has flourished among engineers and doctors, but not among teachers (or nurses, since their initial training has in the last generation been transferred into the university). One strength of the apprenticeship system is that it socialises its members into the practice of collective learning-in-doing, which is one of the cornerstones of knowledge creation by practitioners as well as continuing professional development through on-the-job learning. The dominant theories of learning in formal educational institutions generally, and in the training of teachers in particular, have been concerned with the acquisition of formal, explicit and codified knowledge, taking place in special, segregated places (classrooms), and arising out of formal programmes of work (a curriculum) taught by a pedagogical expert (a trained and qualified teacher). Apprenticeship learning takes a very different form, as shown in Table 1 of Chapter 2.

Apprenticeship, a valuable introduction to collective on-the-job knowledge creation, has been neglected in education in favour of learning in institutions...

The theory of situated learning (Lave and Wenger, 1991; Lave, 1993; Wenger, 1998), by contrast, is grounded in the study of apprenticeship systems. It argues that knowledge is a matter of achieving competence in a field one values, and that acquiring this knowledge is a matter of participating in a group who have already competence, and who are willing to allow the learner to progressively participate in their community. The closeness to an apprenticeship system is immediately obvious. The "masters" are held to be the fully fledged members of a "community of practice". Novices want to exercise the knowledge and skills of the full members, and they acquire them by being allowed to participate in the community legitimately, but initially somewhat peripherally. Learning is an outcome of working, not just an input to it. Over time and through supervised observation and practice, in which tacit knowledge is assumed to be critically important, they move from the margin towards the centre by increasing participation in the community of practice. Learning is fused with work; acquiring knowledge is fused with a changing identity (becoming, and thinking of oneself as, an engineer or doctor) for learning to *do* is simultaneously learning to *be* and to *belong*. This approach not merely rehabilitates the importance of apprenticeship as a sophisticated form of teaching and learning, but potentially offers a bet-

... yet as a model it enables workers not only to learn by doing but to join a community of professionals with a shared competence base...

ter theoretical basis for many types of learning, especially informal and incidental learning, which will characterise lifelong learning in knowledge economies (Fuller and Unwin, 1998; Guile and Young, 1998).

... but has failed to make much progress in education because academic teacher educators have separate professional cultures from those they are training.

This perspective on learning is now becoming familiar in the industrial and the knowledge management literatures, since it both reflects and illuminates existing practices there and can promote new insights and novel research approaches (*e.g.* Kogut and Zander, 1996). It made some early impact on educational research and thinking (*e.g.* Resnick, 1989), and may well provide the theoretical rationale for innovative schools, such as the experimental lycée near Futuroscope, Poitiers, France, where students choose their own projects for one fifth of the timetable. However, it has as yet exercised relatively little influence on the initial training and continuing professional development of teachers. This may seem surprising, until it is remembered that this is not how schoolteachers have been conditioned to think of learning or how teacher trainers conceptualise their work with teachers. The relationship of university-based teacher-trainers (who are also often educational researchers) to practitioner-teachers is not at all like that of master to apprentice, because the former belong to *different* communities of practice. Trends in initial teacher training in several countries are placing novice teachers in schools for longer periods of training under the supervision of practising teachers, which is in the same community of practice, as any student or trainee teacher is supremely aware. If there is a parallel movement to locate more research in schools and to strengthen the role of practising teachers in that research, then the initial training and continuing professional development of teachers will draw closer to the practices that are more common in industry and in hospitals.

A positive development has been to link teacher learning more with that of the whole school, creating a basis for managing knowledge capital...

In recent years the professional development of teachers has become closely linked to strategies for school development (OECD, 1998*b*). There are several strengths to this approach: it links teachers' learning to the aims and objectives of the schools; it focuses on improving the quality of teaching to enhance students' learning and achievement; it encourages collaboration and peer support among the staff of the school. The characteristics of this school-focused strategy for professional development should ideally include:

– An experimential focus on the concrete tasks of teaching, grounded in and derived from teachers' work with students.

– An emphasis on inquiry, reflection and experimentation, and collective problem solving.

– Attention to relevant research and the evidence base for teachers' practices.

– Collaboration among the teachers, with a focus on teachers' communities of practice rather than individual teachers.

This is a strong base for the development of what to most school principals would be novel approaches to the management of knowledge capital, including school-based research and development, and the OECD report (1998*b*) contains some significant innovations, including: new ways of linking research to professional development and the identification of good practice in Luxembourg; teacher networks in the United States; problem-based learning for teachers in Sweden; and work experience for teachers in private companies in Japan.

During the next decade universities are likely to follow the school sector in linking the professional development of staff much more closely to institutional development. In the rapidly changing conditions of the transition from elite to mass systems of higher education, including competition between universities within countries as well as competition between countries in the recruitment of overseas students, there will be increased pressure to create and disseminate new knowledge about effective – and cost-effective – teaching and learning under these novel conditions. Research into higher education may earn a higher status than it has hitherto enjoyed (see Kogan in Part II).

... and universities, under competitive pressures, are likely to follow suit...

Even more important, the transition from the university to the world of work will come under scrutiny for two main reasons. First, many graduates find that their undergraduate education does not prepare them adequately for the demands of their job in terms of problem-solving, decision making and team working; and secondly, it does not prepare them for the intensive on-the-job learning which is a strong feature of both lifelong learning in general and knowledge creation in particular. Candy and Crebert (1991) have explored the differences and discontinuities between the world of university and work, some of which are set out in Table 3.

... particularly in order to improve preparation for work, in terms of general skills and learning strategies that work beyond the precise discipline of academic study...

Table 3. **University *versus* work**

Student-as-learner	**Graduate-as-learner**
curriculum-driven	task-driven
work to pre-set educational objectives	work without pre-set learning objectives
learning is explicit and self-conscious	learning is implicit, informal, un-self-conscious
solve problems in terms of their theoretical coherence	solve problems in a practical, cost- and time-efficient way
apply abstract intellectual processes to solve them	apply lateral or critical thinking processes to solve them
express ideas and thoughts in writing	express thoughts, ideas and solutions orally
depend on external evaluation	use self-criticism and self-evaluation
develop long-term study projects	work to short-term goals
introverted and isolated study habits	be extroverted and gregarious in work habits
jealous and protective of personal research	share outcomes with colleagues
inter-personal skills not developed	team skills at a premium

It is clear that the context of teaching and learning in university tends not to be one in which students easily acquire the flexibility and creativity to enable them to adapt to, and be successful in, the ill-defined, ambiguous and open-ended work situations encountered by new graduates. If the students have learnt how to learn, it may well be in the form of sound study skills, which is not at all the "learning how to learn" which employers increasingly expect in the knowledge society. The learning strategies which served them well as students may be inappropriate in the messy, unpredictable world of work and so somehow have to be replaced by new ways of learning. "Learning how to learn" will need to include how to make the most of the informal learning which is so important in contexts outside formal education and the depth and significance of which tends to be grossly underestimated by most people (Hager, 1998).

Candy and Crebert suggest that changes in both the academy and workplace are needed to support the transition. Universities should focus more on process-based rather than content-based learning; cross-disciplinary projects; experience of peer-evaluation; opportunities for teamwork; off-campus, co-operative education with industry; simulations of professional problem-solving. Employers need to give academic staff more regular and sustained opportunities for experience at the workplace as well as provide

... requiring universities to broaden their methods and employers to improve academic links and graduate induction.

better "sliding scale" induction programmes for new recruits. All such measures would probably increase the capacity of new graduate workers to participate more fully in various forms of knowledge production, diffusion and application.

Change pioneers are emphasising the mentoring and coaching of teachers as part of continuing development, not just induction, to help spread tacit knowledge...

Many professional schools are leading the way to new forms of teaching and learning in higher education. In teacher education, a particularly important development is the rapid growth of schemes of mentoring and coaching, not just for novice teachers, but as a form of lifelong learning for all teachers. In rapidly changing conditions, all teachers need regular opportunities for continuing professional development under the guidance of outstanding practitioners towards the highest levels of professional judgement, which, because of the strong artistic and tacit nature of the knowledge and learning involved, cannot be taught but can be coached.

> Making a "right" decision in any clinical encounter is a more complex and less certain affair than applying a general law of science to an instance of that law in operation (...). A right action, in this view, is an action that conforms best with the available scientific information and technology adjusted to the particular needs of *this* patient. It is not a general statement of the scientific principles of diagnosis, prognosis, or therapeutics applicable to *cases* like this. It is rather a statement of how those principles are optimised in choosing an action in the context of age, sex, occupation, severity – all those particular things that make this patient an individual, not just the workings of a scientific law or mechanism (...). To achieve this end medicine uses knowledge of many different kinds: the morphology of medical decisions is a mosaic of several kinds of knowledge (...). Yet the conditions that assure optimal decisions are just beginning to emerge (Pellagrino, 1981).

The principles involved here can be applied across a wide range of professional training, including the development of teachers, of course. The lesson is that mentoring and coaching, which are powerful means for transferring knowledge, and especially tacit components, should be part of training from a very early stage, probably beginning at school level, to provide a foundation for lifelong learning in which the teaching and learning of tacit knowledge are seen to be an inherent part, and particularly vital in the acquisition of expertise.

... which in turn should equip teachers to help their own students to learn how to learn; this involves a new apprenticeship, not of craft skills but of meta-competencies.

As teachers at all levels of education service become attuned to professional development through mentoring and coaching, the art of teaching students to learn how to learn, and to develop the meta-cognitive skills or meta-competencies to do so, which is such a key feature of successful learning economies, may be easier to acquire. For it is unlikely that these skills and capacities, once their nature becomes clearer through research, could easily be taught through a didactic mode. Rather they need to be *modelled* by the teachers. Students acquire such learning in an apprenticeship mode, with the professional teachers serving as "masters". This is a radically new version of apprenticeship, one in which the masters' skills are not traditional ones inherited from the past, but newly acquired, highly transferable skills that are essential to workers in the knowledge economy. The creation and then the practice of such attitudes and skills through modelling will be the first of the two outstanding challenges to teachers in the early years of the new millennium. The second is discussed in the next section.

Integrating knowledge capital and social capital

The concept of social capital has, during its short life, acquired a range of meanings. In essence, it has a *structural* aspect, by which a person's or organisation's social capital consists of connections to other persons or organisations. In this sense those who are embedded in networks have high levels of social capital There is also a *cultural* or *relational* aspect in that social capital can refer to norms of reciprocity, mutual obligation and trust between people or groups. The two aspects are often combined, especially where social capital refers to the extent within a community of mutual aid, civic engagement and participation in voluntary associations.

Social capital refers to a person or organisation's networks, and to collective social behaviour…

The structural and cultural aspects of social capital are clearly linked, in that social connections and networks are, at a common sense level, likely to be associated with relationships of trust. Trust encourages co-operation which strengthens the social connections involved. Within such relationships, there is likely to be a sharing and exchange of knowledge capital. In short, here is

… with networks and behavioural norms building on each other's strengths, and thereby enhancing knowledge transfer…

> (…) a dialectical process in which social capital is created and sustained through exchange and in which, in turn, social capital facilitates exchange (…) [and so] social capital influences the development of intellectual capital (…) [and] the co-evolution of these two forms of capital may underpin organisational advantage (Nahapiet and Ghoshal, 1998).

High levels of social capital within and between organisations thus supports the kinds of exchange that characterise the process of knowledge creation as described in the Nonaka and Takeuchi (1995) model or the transactions of knowledge transfer by people and organisations in networks.

Recent studies indicate that, as the above conceptual scheme would suggest, high levels of social capital in companies are associated with high levels of performance and successful innovation. This is argued at the theoretical and anecdotal level, as well as the empirical level, and for social capital operationalised and measured as trust or as networking (Burt, 1992; Sako, 1992; Fukuyama, 1995; Kramer and Tyler, 1996; Shaw, 1997; Pennings, Lee and van Witteloostuijn, 1998; Tsai and Ghoshal, 1998; Fountain, 1998). In the light of this literature, Saxenian's account of the advantage of Silicon Valley over Route 128, discussed earlier, can be understood in terms of the former's higher level of social capital which supported superior exchange and exploitation of knowledge capital.

… as demonstrated in practice by the association of high social capital and successful innovation.

Here also is a rich source of hypotheses about the interaction of social and knowledge capital in educational institutions. In many countries schools now find themselves in a turbulent environment of continuing reform and restructuring and in some countries schools are subject to parental choice and thus to competition. These are sometimes held to impede educational innovation, but one lesson from high-tech industry is that this need not necessarily be so.

In education, a more turbulent, competitive environment may stimulate innovation as networks are widened and strengthened…

> Both the rivalry and the trust that co-exist in successful partnerships (…) have a common origin, that is the needs for firms in high-tech industries to accumulate and apply new knowledge at a very fast pace. This goal can be achieved by acting on two main control variables: on the one hand by regulating the complexity of the environment in which the firm operates and on the other by modifying its repertoire of available skills and invisible assets at hand. From this perspective, alliances are seen as competitive moves to survive and grow in a turbulent environment, for they allow firms simultaneously to simplify their relevant environment and enrich their

internal competencies so that the gap between environmental complexity and the firm's capabilities to face it are sensibly reduced (Ciborra, 1991).

... but this needs to involve replacing eroded social capital...

For some social critics, especially Robert Putnam (1993, 1995), it is not simply that the environment of schools or firms is turbulent, but that in many countries social capital, and its elements such as social trust and civic engagement, are being eroded on a massive scale. Changes in patterns of work, pressures on the nuclear and extended family, and declining commitment to, and trust in, many public institutions and services, all contribute to this process, by which

> (...) the individualisation of work and the undermining of social organisation based on work is not-re-equilibrated by families, communities, and public institutions. T*he whole system of relationships among the cornerstones of our societies is at stake*. Piecemeal measures destined to increase the number of jobs or train workers better will not be able to address the whole set of interactions triggered by the process of technological and cultural change that are at the root of the information society. We must design new public policies, business strategies, and personal projects. These must aim to reconstruct a set of economically productive and social fulfilling relationships between work, family and community in the new socio-technical paradigm (OECD, 1997).

... which schools are well-placed to do, but there is a need to be inclusive, and for social capital to be high among staff.

Schools are an important institution that can help to generate and sustain social capital. Since the possession of social capital by students contributes, as does cultural capital, to educational achievement (Coleman, 1988), it is important that the school provides disadvantaged students with social capital as a means of raising levels of cognitive outcomes, and thus some protection against social exclusion. Yet if social capital is in general decline, as Putnam contends, then *all* students need the school to enrich their social capital. In part this can be done through the teaching of citizenship, especially where this is associated with active participation, as in school councils for students or in community service supervised by the school. In line with the argument in this chapter, it can be hypothesised that a school with high social capital among the staff will not merely be more effective and more competent in knowledge management, but will also be a community which, through its ethos and the modelling by teachers, transmits to its students the importance and power of norms of reciprocity, relationships of trust and skills of networking. The capacity of schools to generate and sustain social capital may well depend upon the character and quality of the partnerships that schools make with families, employers and external communities. We are simply at the beginning of understanding the relationships between education and social capital, especially in the light of lifelong learning (*e.g.* Schuller, 1997; Schuller and Field, 1998).

Designing an infrastructure to support knowledge management

To serve tomorrow's needs, educational institutions require a conscious culture change to manage knowledge better...

An infrastructure to support knowledge management in education will be needed in national, regional and local forms. In the absence of such an infrastructure, schools, colleges and universities cannot truly become the learning organisations that are essential to "schooling for tomorrow". Better knowledge management will not arise spontaneously in schools. As was the case in business and industry, it will require champions to exercise the necessary leadership which is involved in changing the culture of schools.

... first at the national level...

At national level, an appropriate infrastructure will consist of:

- ICT networks linking educational organisations to one another and to their partners.

– A system for training the leaders, managers and senior staff of educational organisations in knowledge management.
– The provision of resources to support knowledge management.
– Delegation to the regions of powers and responsibilities for supporting networks and encouraging knowledge management.
– Establishing forums to provide strategies and guidance for educational R&D and research foresight exercises.

... and secondly at the regional and local levels...

At regional level and at local level (district offices, local education authorities), it will consist of:

– Providing local networks and intra-nets, with active support for them in the form of facilitators and co-ordinators.
– Mechanisms for co-ordinating knowledge management, research and development and continuing professional development.
– Acting as a broker for new partnerships between schools and universities.
– Between schools and companies with experience of, and skill in, knowledge management, with particular attention to creating an appropriate culture.
– Arranging local forums for debate and exchange.
– Identifying and disseminating best practice in knowledge management in educational organisations.

... with knowledge-intensive industries demonstrating the power of local interactions across small businesses or schools...

The education system can learn much from knowledge-intensive industries at the regional and local levels.

> The contrasting experiences of Silicon Valley and Route 128 suggest the industrial systems built on regional networks are more flexible and technologically dynamic than those in which experimentation and learning are confined to individual firms. Silicon Valley continues to reinvent itself as its specialised producers learn collectively and adjust to one another's needs through shifting patterns of competition and collaboration. The separate and self-sufficient organisational structures of Route 128, in contrast, hinder adaptation by isolating the process of technological change within corporate boundaries (...). Geographic proximity promotes the repeated interactions and mutual trust needed to sustain collaboration (...). Policies to support network-based industrial systems are most effectively achieved at regional rather than national or sectoral level. Regional policy serves best as a catalyst – stimulating and co-ordinating co-operation among firms and between firms and the public sector. Rather than being orchestrated as top-down intervention or bureaucratic guidance, policy initiatives should evolve as interested local parties exchange information, negotiate and collaborate. The starting point for a regional industrial strategy is fostering the collective identities and trust to support the formation and elaboration of local networks. By providing forums for exchange and debate, policy makers can encourage the development of shared understandings and promote collaboration among local producers (Saxenian, 1994).

Obviously schools are much more like small firms than large ones, and personal contact within these networks is likely to be critical.

> Personal trust was important and, as a consequence, such small-firm networks were centred more on relationships with particular individuals

within external organisations, rather than more formal, bureaucratic, faceless linkages at the level of the organisation. It is also important to note that the network of external relationships built, nurtured and mobilised by this sample of innovative small firms was frequently found to be centred largely around one individual: the entrepreneur (Conway, 1997).

The school principal may well be the "boundary spanner" who makes or facilitates personal links within networks of innovative schools; if so, it will be the task of local and national education authorities to devise means by which principals can be supported in the activities of spanning boundaries within networks to promote knowledge transfer and innovation. Investigating which patterns of linkage and flow between schools are related to success in innovation, which may mirror some of the findings from industrial research (*e.g.* Heydebreck, 1997) is an important task for university-based research.

… and governments needing to recognise that social capital is critical to the knowledge equation, alongside stocks of knowledge itself and worker competence.

Governments, both national and regional, will, in forging educational policies that are influenced by trends and developments in knowledge-intensive industries and professions, need to take account of the relationship between different forms of capital – human capital, knowledge capital and social capital – since it is from their interactions that the highest social and educational leverage can perhaps be obtained.

So far, almost no explicit attention has been directed toward the effect of social capital on innovation (…). The glue in the new political economy is the trust, or enlightened self-interest, among decision-makers that makes collaboration feasible (…). The notion of social capital extends our understanding of "co-operation" or "collaboration" in two significant ways. First, linking co-operation to the economic concept "capital" signals the investment or growth potential of a group's ability to work jointly. Second, the concept identifies the *structure* created from collaborative effort as capital (…). Thus, specialised technological knowledge – and innovation – increasingly reside in small and medium suppliers whose "research and development" takes place in team-based configurations on the shop floor rather than in corporate laboratories staffed with scientists working on long-range basic research. Compared to large, hierarchical structures, network structures can more effectively scan the environment for changes, more accurately interpret environmental change, and more creatively and adaptively craft responses to change. Better scanning means stronger capacity for timely and accurate problem recognition (…). Actors in a collaborative network exhibit an efficient form of collective learning. They learn of new technologies, opportunities, the outcome of transactions, and challenges more quickly because of density of interaction within the network. Learning is of a higher quality because it is subject to discussion and debate among horizontal counterparts whose perspectives and backgrounds may differ (…). Dense social networks can encourage experimentation and entrepreneurship among actors because of the mix of collaboration and competition within the network. In fields in which knowledge is distributed across a wide range of organisations and where scientific and technological knowledge is critical to competitiveness, innovation is located in the network rather than within individual firms (…). The federal government should aggressively provide incentives and information to promote the use of networks and consortia in order to connect firms to universities, national labs, and state and federal partnership programmes (…). The federal level can explicitly seek to build social capital among key stakeholders by providing a forum for dialogue and discussion to search for and establish consensus as a basis for collaboration (Fountain, 1998).

This was not written with educational institutions in mind, but in the light of this chapter's analysis, the words may be read as a call for government action to help the education service towards more effective "schooling for tomorrow" in societies that thereby become richer in social and intellectual as well as human capital.

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Chapter 4

AN EMERGING RESEARCH AGENDA

More needs to be understood about knowledge and how it is used in education. This chapter suggests an agenda...

On the eve of the 21st century, many commentators talk and write about the knowledge-based economy, but few seriously conceptualise or describe what is meant by this term. There is an urgent need for analysis that identifies both its characteristics and dynamics and the most appropriate routes for policy development. Otherwise the "knowledge economy" will remain a slogan without substance. This concluding chapter suggests some of the areas in which new knowledge about knowledge and learning processes in education will be useful. As researchers in many disciplines become more interested in these issues, they will also become an important part of the agenda of the OECD as an organisation, again from many disciplinary perspectives.

... to follow on from the above analysis, which has only started to overcome barriers to understanding.

Serious barriers have helped prevent knowledge, and indeed learning, from being analysed with sufficient precision. First, they are very difficult to measure (see Foray in Part II below). Secondly, the way in which we understand how knowledge is created, transferred and used remains partial, superficial and fragmented across several scientific disciplines; basic concepts have been expressed and interpreted in a variety of ways. So the production of knowledge remains a "black box" which we find it difficult to see inside. This report has tried to start opening up this box of "knowledge about knowledge", but a great deal more work is needed if we are truly to open the box wide. A new research agenda is therefore needed to improve our understanding of knowledge and learning processes in education and in a broader context of the knowledge economy.

In this quest, different disciplines need to come together, and educators should draw from other sectors and learning environments...

In pursuing this agenda, it will be important to bring disciplines together into a closer mutual framework of understanding. The present work, pursued by an educational unit within an economic organisation, has started to show how greater emphasis on the characteristics of knowledge and learning can complement economic traditions of analysis, which tend to treat knowledge as homogeneous. More needs to be done to connect knowledge about learning/knowledge with knowledge about the economy and organisations. Such an approach also has implications for the analysis of the education sector, which has a great deal to learn about how knowledge is created, transmitted and applied in other sectors. It must do so in the first place to strengthen the overall conditions of knowledge management in schools, colleges, universities etc. In the second place, only by drawing widely on experiences in different settings and organisations can educators meet the challenge of offering lifelong learning for all and prepare students for the high-skill knowledge economies in which they will work.

... building on the cross-sectoral insights presented in this report.

Although it remains a preliminary overview of the knowledge processes at work in different sectors, the report identifies a number of ways in which micro-level or sectoral understanding of the knowledge-based economy is important, alongside the more macro-level insights. These insights are valuable for governments, economic sectors, and public and private enterprises and institutions when they are seeking to improve their knowledge and learning performance, which is increasingly important in order to stay competitive.

Research can be directed at: – knowledge management, – its measurement, – its contribution to innovation in education, – educational R&D, and – learning sciences.

Five areas have been identified below as a framework of research issues to improve our understanding of knowledge and learning processes in education and in a broader context of the knowledge economy and society. First, the way in which knowledge and learning are managed by modern organisations and in the education system. Second, ways in which this knowledge can be identified and measured, whether by the organisations themselves or by policy makers and the wider public. Third, specifically in education, how improved knowledge management may create organisations that become more effective at learning and innovating than they have been in the past. Fourth, the challenge to R&D systems within education to become a more effective part of knowledge management in this sector, potentially by creating new structures that bring them closer to policy making and practice. Finally, the pursuit of a specific breakthrough in the knowledge used by education, by bringing together brain specialists and learning specialists to pursue a better understanding of learning processes.

Area 1: Management of knowledge and learning

The above cross-sectoral analysis could be developed further.

A comparative study of the production, mediation and use of knowledge in different sectors has been undertaken in chapter 2 to achieve two purposes: first, to illuminate the general nature of these processes in modern economies; and secondly, to clarify how the education sector manages knowledge and how it might do so better. The comparison gives some understanding and tools that allow people who work in a firm or institution in a sector to see these processes more clearly in relation to other sectors. Such an approach could certainly be developed further.

Knowledge management has replaced the scientific management of industrial processes…

The management of knowledge and human resources has, in several economic sectors, become the drivers of production. In 1900, "Scientific management" studied and aimed to improve factory processes; in the "knowledge intensive firm" of 2000, managers aim to improve the production and use of knowledge. Good knowledge management involves the recognition and use of intellectual capital, the creation and sustaining of a knowledge culture and the construction of a knowledge infrastructure that can be harnessed effectively both within and outside a firm's institutional boundaries.

… but knowledge is less amenable to manipulation than physical procedures.

Yet knowledge management resists the engineering and planning tools available to scientific management of physical processes. As previous chapters have shown, knowledge is "slippery" and closely linked to the people who hold it; its categories and meanings change frequently. The expert systems movement of the 1980s confirmed how difficult it is to create rules that cover even narrow knowledge domains and even more difficult to update and modify the structure. Moreover, because the position of knowledge often is closely linked with power structures within an organisation, changes introduced by knowledge management can be seen as a threat and sometimes met with resistance within the organisation. These factors will have to be taken into account in the analysis proposed below.

Limitations in knowledge management in some public services are regrettable…

Some of the largest public services like the education and health sectors seem in some respects to lag behind in the development of an innovative knowledge infrastructure. This might be seen as unfortunate, as the management of knowledge is proving a key instrument in the constant strive for innovation in the competitive environment of private business and can similarly be a powerful tool in the steady improvement of public services.

ON THE RESEARCH AGENDA:

Needed: ***Case studies of knowledge management at the firm or organisation level in different sectors and countries, to set up benchmarking criteria.***

Issues: ***How can organisations use knowledge more efficiently? What are the differences in knowledge management between the public and private sectors? How do different professions manage knowledge? What are the characteristics of a learning organisation?***

... and it will be a big task to steer them towards a new mode of knowledge production and use...

Such work will build on the progress already obtained in the analysis of this report and it will continue the work on the characteristics of and changes in the high-tech industries for possible lessons for education and other sectors in how to manage knowledge. It will be a tremendous task for the education sector to move towards a Mode 2 knowledge production in Michael Gibbons's sense: that which is applied, problem-focused, trans-displinary, demand-driven, entrepreneurial, accountability-tested, embedded in networks. In the higher education and lifelong learning market, increasing competition is likely to make it all the more important that institutions produce, transmit and use knowledge efficiently.

ON THE RESEARCH AGENDA:

In progress at the OECD: ***A major cross-directorate project, "The Growth Initiative", has been launched to identify the determinants of and policies to strengthen overall economic growth. This project will, among other topics, explore the impact of innovation, knowledge and human capital on economic growth. There will be focus on the nature of human and social capital and evidence of the link between them and economic growth as well as other social outcomes.***

Educational issues: ***How can schools and other educational institutions develop a commitment to knowledge management, which at present is at best uneven? What are the costs and benefits of knowledge transfer in education? Can education institutions be given incentives to promote knowledge management and learning organisations? This again will have consequences for curriculum, teacher training, organisation of schools, etc.***

... which is needed to bring together social capital with human capital, along with development strategies being pursued across the **OECD.**

Learning organisations in which networking and effective management and sharing of knowledge occur can act as important engines of economic growth and social development. There is an important link between human and social capital, where the latter constitutes norms of trust, civic engagement and capacity to enter into fruitful social relations. Social capital can underpin effective learning and knowledge creation and at the same time the education and learning environment can foster social capital. Human capital investment can also play an important role in sustaining social infrastructure and through it economic growth where there is evidence of erosion of social cohesion and social capital over time. Policies that influence the production, transmission and use of human capital and knowledge in strategies of economic growth and social cohesion are being addressed across the OECD's work.

Area 2: Towards new measurements of knowledge and learning

Knowledge measurement can help identify gaps that need to be filled...

At the policy level, measurement and indicators can help policy makers to identify where outcomes fall short of expectation, or which intermediate factors determining outcomes require most attention. For these reasons, it is important to be able to estimate with greater accuracy the amount of knowledge and learning in particular sectors, and the rate at which it is being produced. If knowledge and learning drive productivity, as the notion of the "knowledge-based economy" suggests, identifying and filling the gaps should be beneficial.

… but has so far been limited mainly to R&D and formal education.

Considerable progress has already been achieved in some aspects of the measurement, for example in measuring R&D and basic formal educational activities. The OECD has been the driving force in co-ordinating and setting up internationally comparative indicators in these areas. But Professor Foray's analysis in Part II below demonstrates convincingly that the use and creation of knowledge overall are poorly measured. Thus, there is a need to develop new indicators.

It may be easier to measure conditions favourable to knowledge creation than knowledge itself…

One problem with defining a "common" stock of knowledge is that access to knowledge is in fact limited (see Chapter 1 above). A second problem is in classifying it by its economical usefulness. It is therefore difficult to produce simple, aggregate measures of either the stock of knowledge or the rate of its formation. It is, however, possible to produce instead indicators of the conditions favourable to its formation.

ON THE RESEARCH AGENDA:

In progress at the OECD: ***Investigation has begun in several Directorates of OECD into areas such as networks and clusters, which facilitate innovation, collaboration and the collective development of knowledge; mobility of highly qualified persons; the amount of job-related training; the development of frameworks for measuring company level intellectual capital; and the rate of enterprise creation and level of innovation across different sectors.***

… but new ways of measuring competence are being developed…

Measurements of some of the crucial aspects of learning may be even more difficult. It is for example difficult to capture competence building through learning. Many kinds of competence can only be revealed through application, rather than through testing in artificial contexts. But some forms of assessment can look more directly at competence than traditional tests based on learning curricula.

ON THE RESEARCH AGENDA:

Coming soon at the OECD: ***In the OECD Programme for International Student Assessment (PISA), whose first full assessments are taking place in 2000, new measures of student cross-curricular competencies are being developed. These will give some insight into the capacity of students to solve problems in real life situations, such as in the workplace and the community. These measurements are important to get a better understanding of competence building by individual and its relationship to formal classroom learning.***

… and there is scope to develop indicators further, provided many disciplines are involved, and international comparisons take account of cultural contexts.

A jointly organised seminar by the National Science Foundation and the OECD on Measurement of Knowledge in Learning Economies, May 1999 gave some lessons on how to develop the work on new indicators on knowledge and learning. First, it is important to have a cross-disciplinary approach in the work on constructing new indicators. It was emphasised that it should be carried out only as a part of an exercise that seeks to improve understanding of learning and technology *systems*, and not just crude quantities of activity. In particular, the case-study approach, focusing on particular sectors and learning systems in countries, was seen as a fruitful way of developing a qualitative understanding that would help make sense of quantitative measures. Second, national and local institutions and institutional cultures do matter. What makes the education and learning systems of some countries work better than others, for example, can be a matter of local practice and social and/or cultural capital, rather than simply the overall volume of resources invested. These two lessons are important to keep in mind in the work with new indicators and especially in analysing and interpreting the indicators.

ON THE RESEARCH AGENDA:

Issues: ***Some of the challenges for the OECD will be to describe informal processes of the production of knowledge and learning that can explain performance. For example, can indicators of tacit knowledge be established? Can we get a better grasp of, which kinds of learning are important for which kinds of innovation; How can we measure the performance of learning organisations? Can indicators be developed which show the role of social capital in the promotion of economic development including learning and innovation? Empirical work on such questions is still in its infancy, but is starting to get underway.***

Area 3: Policies of innovation in education

Innovation can be promoted not only in schools, but also elsewhere in education.

Some of the research issues mentioned under area 3 will be taken up in the OECD/CERI project on "Schooling for Tomorrow". In this report, much of the discussion of the promotion of innovation has focused on schools, though many of the same arguments apply to the other levels in education systems. While there is often greater diversity of institutional forms and partnerships in tertiary education, certain practices relating to teaching and learning are often even more traditional at this level than in schools. Hence, the research agenda below for the promotion of innovation is not restricted only to schools.

Little is known about the complex ways in which knowledge is transmitted in education, or the costs and efforts involved...

The report has shown the inadequacy of linear models relating to the production, use and transmission of knowledge. Innovation based on interaction and institutional-level innovation is more appropriate for today's knowledge societies than a model of bureaucratic control. Particularly inappropriate is "factory" models of schooling, rigidly "processing" students in terms of standardised inputs and outputs. The most complex, and least understood aspect of the innovation process is the final phase of "institutionalising" a change, by making it part of routine practice, yet not in a way that undermines the very culture of innovation. In this process, very little is known about the "stickiness" of knowledge in education – the cost of efforts and resources required for knowledge transfer – whereas there is some research on this for other sectors.

ON THE RESEARCH AGENDA:

Ongoing work: ***Current work is aiming to create a deeper understanding of new models of schooling, especially those that function within mainstream systems rather than on their periphery, and of the process and institutionalisation of innovation. Empirical clarification of the "stickiness" of knowledge in education, and the extent to which this represents a major barrier to innovation, would be valuable developments of this work.***

... but it is clear that many schools are not "learning organisations"...

This report has discussed the way in which schools operate as organisations. While they may be characterised as either "hierarchical" or "flat" organisationally, many cannot be realistically described as "learning organisations". The nature of work within them frequently is highly individualised, and relatively low resources of time and money are devoted to the learning undertaken by personnel and management. There may be powerful disincentives for teachers to engage in activities other than those perceived as the "core" teaching time on task, such as R&D and collective planning. Basic characteristics of dynamic organisations drawing on experience across different sectors – incorporating features such as teamwork, cohesion etc. – stand at odds with the organisational models typifying many educational institutions. This is not only about teachers and support staff: a key role in successful innovations is played by users – the students.

... and the ways teachers share their craft knowledge needs attention...

A considerable degree of attention has been devoted in the report to the nature of teacher work and the organisation and management of learning and knowledge within education. Teacher knowledge can often be characterised as a "craft", based on tacit, non-technical and highly individualised knowledge. This is a reflection in part of initial socialisation into teaching, in part of the cultures and organisations that prevail in schooling. There is considerable interest in examining new forms of professional identity and operations, opening up individualised practices. The role of networking – within and between institutions, and with professionals in other sectors – deserves particular attention.

ON THE RESEARCH AGENDA:

Issue for further investigation: H*ow do versions of professional identity in various countries and educational settings influence their collective management of knowledge*? T*he extent and forms of networking warrants close attention, including policies and initiatives that have proved successful in strengthening networking*.

... but freeing schools from bureaucratic constraints raises equity issues.

Important equity considerations are raised by the promotion of innovation in education, with its corresponding de-emphasis of bureaucratic standardisation – which has in general been put in place to provide equality of opportunity. Is there a danger that more innovative, interactive forms of education may disproportionately favour the already-advantaged and, if so, what might be done to address these risks? Alternatively, situations of adversity may also promote innovative responses.

ON THE RESEARCH AGENDA:

Issue for investigation: W*hat is the social distribution of innovation, and how strong is the risk that new schooling models will widen existing barriers and gaps*. H*ow can policy promote innovation in areas and for students most at risk of exclusion*?

ICT can play a crucial role in radical change.

The role of information and communication technology (ICT) has been stressed as an integral element of all these issues. The report has highlighted the "exogenous" role of ICT in education as a major new "knowledge mediator". It has pointed to some key roles of ICT – in extending opportunities for networking by both students and teachers, in forming a key part of radical change within school management, and in potentially opening new forms of teaching and learning, to existing and new students.

ON THE RESEARCH AGENDA:

Ongoing work: T*he ways in which schools are using* ICT *is being investigated, with particular emphasis on examining why the* ICT *has not always made the impact on the nature and outcomes of education that has been often expected, and what policy measures could improve its use*.

New forms of learning require teachers to make big changes, for which they may best learn from each other.

It is widely acknowledged that lifelong learning and preparation for the knowledge economy call for student-centred, task-oriented, co-operative forms of learning, with an emphasis on acquiring the skills and habits of further learning. This presents a radical challenge to a great deal of practice, especially "factory" models of teaching based on very different assumptions. This challenge is increasingly acknowledged in principle; changing practice is much more difficult to achieve. There is value in understanding and promoting "apprenticeship" models of learning, where practice and integration into communities of expertise are powerful characteristics.

ON THE RESEARCH AGENDA:

Issues for investigation: *The main competences actually acquired through education, and their match to the needs of lifelong learning and the knowledge economy, remain poorly understood. Little research has yet integrated the implications of work-based and informal learning with that which takes place in formal education. In pursuing a better understanding, CERI will need to identify appropriate policy strategies for change.*

Research could usefully address the broader policy environment and pressures within which educational institutions operate. While official aims may endorse the need for innovation, other aspects of policy may be creating pressures that make innovation difficult to realise. Changing patterns of formal governance, including devolution to school-level decision-making and the diminution of central regulation, does not necessarily result in greatly enhanced freedom of operation, while social, parental, and student demand may be more for the familiar than the experimental.

It is also worth researching the impact of decentralisation and related reforms on school knowledge management.

Area 4: The new challenges for educational R&D systems

This report has shown that governments urgently need better knowledge bases for determining educational policy and practice in an increasingly interconnected world. As we have seen in Chapter 2 the rate, quality and success in knowledge creation, mediation and use is relatively low in the education sector compared with other sectors. This report makes a strong plea for strengthening the knowledge management at every level of the education system in order to increase the education system's capacity for the successful production, mediation and application of knowledge.

In light of the weakness of knowledge creation across education…

Education systems in several OECD countries are working on creating a more solid knowledge base on best practices and what works in educational practice. A key issue is how best can policy-makers, educational researchers and teachers unify their efforts to consolidate and strengthen the knowledge base in education. Experience from, for example, the health sector shows that opportunities exist for analysing and developing a more evidence-based research system, which could strengthen the knowledge base in education. The educational R&D systems can play an important role in these efforts.

… there are efforts to strengthen interaction between researchers, policy-makers and practitioners…

Nevertheless, it is still a general perception that the potential contribution of educational R&D has not been fully realised, and that there is some need for restructuring in order to use the funds that are available to educational R&D in the most effectively way. Several studies, including from the OECD, have shown that educational R&D often have little direct impact on educational practice and policy-making. This report clearly indicates that there is no definite boundary between the production of knowledge and its application. Such insights have not so far led to widespread, radical restructuring of educational R&D that brings researchers and teachers into a much tighter partnership, by which they engage in sustained dialogue to design, implement and evaluate R&D projects or researchers move into schools to work alongside teachers as R&D partners. However, such school-based, applied R&D would not replace basic research in universities and research institutes focused on

… but also to rethink systems of educational research, bringing it closer to schools without neglecting work in universities.

education or on relevant disciplines, but would complement and enrich it. In some countries, such as the United States, the United Kingdom and the Nordic countries, the process of reforming the educational R&D system in such a direction has already begun.

ON THE RESEARCH AGENDA:

In the pipeline: ***The CERI will undertake country-based "mini-reviews" on how educational R&D systems are responding to these challenges. On the basis of these reviews an overall overview of the state-of-art of OECD educational R&D systems will be undertaken.***

Area 5: Towards a new research agenda for learning sciences

We understand little about learning and the brain…

The only element that can be considered "stable" in a perpetually shifting environment is the base of the whole learning process: the human brain. A neuroscientific approach to learning still has to be developed. This is a vast uncharted territory.

… and neuroscientists have not talked much to learning specialists…

Most commentators agree that brain research, particularly in recent decades, has not yet found many applications in the learning field. Notwithstanding the remarkable progress in fundamental research, the number of findings that can be exploited or that have been exploited by learning science is still limited. This is probably due, *inter alia*, to the fact that up to now there has been little direct contact between "neuroscientists" and "learning scientists" (moreover, there is little consensus on the *potential* spin-offs from neuroscience for learning science: on one side there is optimism, on the other extreme scepticism).

… so CERI will bring them together with policy-makers in education.

The main role of the CERI will be to bring together scientists in brain research and policy-makers in education in a direct dialog to explore if the new insights in how the brain works would be of relevance for learners, teachers and policy-makers in education.

ON THE RESEARCH AGENDA:

New initiative: ***CERI will launch a new area of work on learning sciences, to establish a direct link between brain specialists and learning specialists. By bringing together people who work in disciplines institutionally and functionally remote from one another, this work aims to create the conditions for the development of research in a new discipline that is greater than the sum of the contributing ones.***

A forum of neuroscientists, cognitive scientists and learning scientists will be brought together to explore new approaches and new ideas about the way the brain works and the learning process. These people will be involved in a dialog with policy makers within the OECD member countries on these issues.

Part II

PRODUCTION, MEDIATION AND USE OF KNOWLEDGE: SOME EXAMPLES

PRESENTATION OF EXPERTS' REPORTS ON THE MANAGEMENT OF KNOWLEDGE

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Knowledge management in the learning society

Part II reports on the work carried out in four high-level seminars organised by CERI at the OECD and co-organised at Tokyo (with the Japanese Ministry for Education, Science, Culture and Sport), Paris at the OECD, Stanford (with the Graduate Business School) and Washington (with the US National Science Foundation). These seminars focused each on a specific theme relating to the production, diffusion and use of knowledge in different sectors. Some 30-40 people attended each of the seminars, two of which (Tokyo, Stanford) were preceded by visits to firms. The papers presented at the seminars were discussed by economists, historians and sociologists, but also by practitioners and policy makers.

The aim here is to present a selection of papers in order to allow the reader to participate "virtually" in the discussions about knowledge management, which assumes that there is an interrelation between production, mediation and use of knowledge. Knowledge management is nothing new. What is new is the awareness that knowledge has to be managed as a resource both individually and collectively by and for the actors who make and are the economy. What is also new is the fact that knowledge is consciously produced and that the users are well aware of this fact and play on it. Sociologists speak of reflexivity to designate this phenomenon, which is particularly visible in the medical sphere or education where "lay people" appropriate, in their own way, knowledge previously reserved to the professions and do so for better or worse.

A two-sided reflection ran though the four seminars.

First, speaking of the production of knowledge explicitly or implicitly recalls the powerful metaphor of production developed by what is known today as classical economics. It states that all economic activity is a conversion of input into output, and this can carry over to the definition of any activity. For example, to treat a patient is to convert someone who is ill into someone who is well; to teach is to convert an ignorant person into a knowledgeable one.

This metaphor leaves in shadow a certain number of far from trivial assumptions. For example, if the difference in firms' performance is considered due to their combination of inputs into outputs, this assumes that there is a system of production in which techniques and knowledge are stable, known, articulated and transmissible. This also assumes that all firms have equal access to this knowledge, that is, that they know how to read and understand "the same cookbooks" and are fully familiar with all the ingredients of success in "obtaining delicious dishes", that is, in offering products and services recognised as of good quality on the market. In other words, knowledge is accessible and transmissible to all. In reality, the situation is more complicated. Aspects of learning, both individually and in general, will play a role. Access to available knowledge will be unequal, and diffusion of knowledge may take place with difficulty or differently.

If this assumption about accessibility is more or less borne out in firms' practice, the issue addressed by the four seminars, that of the production and use of knowledge, becomes more difficult. What is to be understood by "production of knowledge"? Does one produce knowledge as one produces soap or a car? Obviously not: the assumption that knowledge is not a product like others served as a framework throughout the seminars and underlies the various papers. Moreover, when looking at the education sector alone, the difficulty increases, as this is an area where the production function may not be the best metaphor for understanding the activity of teaching. For example, what are the inputs and the outputs? Who are the users: pupils, parents or firms?

The second issue concerns the pertinence of a linear model in which basic knowledge is transmitted chronologically, upstream to downstream, or top to bottom, with a recognised specialisation in tasks and functions. This long-lived idea – that there is a clearly identified and delineated research and development function just as there is a manufacturing and diffusion and distribution function – is one that appears today too simple, even simplistic, in its lack of attention to sociology or history. It should however be noted that the abandonment of the linear model, which is described at length in the first part of this report, was not always possible. Participants were very tempted to find lines of demarcation between scientific knowledge, the domain of researchers, and technical knowledge, the domain of businesses. The discussion of the blurring of borders was often very lively and it must be said that it was in the area of education that discussants wished to out-Herod Herod by maintaining a clear separation between the world of research and development and the world of users. Of course, the situation varies among OECD countries, but, in some, it must be recognised that the users, that is ultimately teachers and professors, appear more as objects of research than as participants in research.

To give an accounting of the different seminars, this part is organised around three themes which structure the various presentations: the argument for the renewal of the conceptual framework that would allow for understanding the knowledge economy; sectoral comparisons that help achieve a better understanding of the education sector; the need to build a new generation of indicators.

Renewing the conceptual framework so as to understand the knowledge economy

When one analyses knowledge as a resource, unquestionably of a very specific type, there arises the issue of its source, its exploitation and its delivery, to use the classical expressions of the value chain described by economists. A discussion arose among economists with respect to the basic division between two modes: the world of objects and the world of ideas. In a stimulating oral presentation at the Stanford seminar, Professor Paul Romer of Stanford University argued convincingly that the participants should work to construct a theoretical framework that would make it possible to understand the development of knowledge economies. For Romer, the distinction between objects and ideas does not necessarily lead to a distinction between public and private goods. Romer said, provocatively, that a shoal of sardines was as much a public good as Thales' theorem if the mechanisms controlling access to the source are null or essentially null; in other words, the distinction between a public and a private good would no longer be a fundamental distinction for economists insofar as it refers to a public policy choice, or to institutional arrangements as Professor David Mowery of the University of California at Berkeley put it when he spoke at the Washington seminar.

For Romer, this distinction has more an institutional, sociological and political basis than an economic one. Taking the position of the devil's advocate, he underscored the lack of tragedy for the "intellectual commons", an explicit allusion to the eighteenth century debates in England which fed the thinking of the founders of political economy. When the number of sheep put to pasture on the commons depended on the dimensions of the fields, political problems of distribution arose: whether to increase the extent of the fields or reduce the size of the flock – a tragic choice. There is no such problem with ideas which do not come up against the question of scarce resources and distribution. Ideas have very specific characteristics and can extend indefinitely. Some can fly far afield, ignoring national borders, while others are embedded in organisations or are "sticky", in the felicitous expression of Professor Eric von Hippel of MIT, who participated in the Washington seminar. Some ideas are easy to convert into human capital, while others are used to redistribute objects, and still others solely to produce further ideas. It is within the framework of this classification of ideas that the separation between tacit and codified knowledge takes on all its meaning. Romer also proposed topics for study to public policy makers by suggesting that they take many more initiatives to encourage the birth and production of ideas, a process which is, by definition, infinite. Policy makers should show imagination and envisage new mechanisms, fiscal but also organisational incentives so as to speed the process.

For example, at the Washington seminar, David Mowery analysed the Bayh-Dole Act* as a mechanism which has profoundly modified the relations between academics and businessmen in the United States. The extension of intellectual property rights to firms that seek to make use of university studies financed by the federal government has had a significant impact on the behaviour of the interested parties. Professor Susanne Huttner, University of California at Berkeley, in her presentation at the Washington seminar, provides convincing descriptions taken from biotechnology to show the impact of this law on the acceleration of the diffusion of knowledge. Such a mechanism has changed in a lasting way the asymmetries in contracts between businessmen and academics. In other words, behaviour can be modified by new incentive mechanisms. What comes into play is a sort of rule of "political" good behaviour in order to define what comes under the heading of public good and what comes under that of private good. This separation obviously refers back to national institutional frameworks. Indeed, Romer raised a far-reaching question: Are we seeing the end of science? The time when the French scientists Pierre and Marie Curie openly communicated all of their work to their foreign colleagues in the name of the universality of scientific knowledge seems to be over. The organisation model defended by the historian and economist Paul David, Oxford and Stanford University, who participated in the Washington seminar, was to some extent questioned by the participants. Is it pertinent today to distinguish, in David's expression, the republic of science and the kingdom of technology? When new institutional arrangement openly encourage (*cf.* Bayh-Dole) the interpenetration of public and private interests, compromises are made between private appropriation of results and the circulation of scientific knowledge. It is these types of compromise that it is necessary to seek to understand and which necessarily require an institutional analysis of the economy.

Professor Richard Nelson, of Columbia University, was among the first economists, along with Professor Sidney Winter, to have called attention to the awkwardness with which orthodox classical theory attempted to address economic change. His analysis is found in an important work which seeks to propose an institutional theory of economic change. It argues in particular that firms can be understood not as combinations of input into output but as organisational capacities. Using work on firm behaviour (Professors Herbert Simon, Richard Michael Cyert, and James March) but also the work of historians like Professor Chandler and economists like Schumpeter, this is pioneering work which seeks to achieve better understanding.

Nelson argues that one can understand the firm's behaviour only in relation to its place in its environment, an almost natural, one might even say ecological, place. He then proposes a more realistic analysis of the firm, whose trajectory can only be understood in its place in an environment, a sector with its specificity and system of values. His is an argument in favour of a sectoral analysis which makes it possible to project trajectories insofar as it is developed in a community of shared practices and values. Airbus and Boeing are undoubtedly competitors, but they belong to the aviation community, and the same can be said of electricians or petrochemists.

In his paper, Nelson came back to the basic issue that concerned him in that earlier work, that is to say his intellectual discomfort with the assumptions of standard theory about the production function. Nelson, along with others such as Professor Kenneth Arrow, Stanford University, a pioneering thinker about the economic consequences of knowledge, underlines the importance of "learning by doing", a kind of knowledge which cannot be transmitted in the form of procedural manuals but only through experience shared between people. Arrow raised this point at the Stanford seminar to "explain" the Silicon Valley phenomenon. He pointed out that direct personal contact, that is, the relations that make it possible to correct reasoning "in real time" and mutual adjustments, are always necessary if an economy is to be efficient.

* The Bayh-Dole Act provides american universities and other research institutions that receive federal money with a specific mechanism for extending intellectual propriety rights to firms seeking to commercialise university inventions.

Professor Bengt-Åke Lundvall, Aalborg University, Denmark, develops the concept of "learning by doing" in his paper. He addresses not the "knowledge economy" but the "learning economy". His work makes use of the distinction between reproducible and non-reproducible knowledge. This distinction, which is different from that between tangible and intangible knowledge, makes it possible to attack in another way the problem of the transmission of knowledge. To transmit is not to communicate; transmission cannot be reduced to a choice of the medium that diffuses new knowledge to receivers ready to absorb it. Transmission involves moving from one state of learning to another. It may be dramatic. For example, in the past, in the dialogue between generations, the older person knew more than the young apprentice and transmitted knowledge through rites of initiation and integration. The opposite case can be seen today, as young people know more about computers than their elders. The older generation, which is not knowledgeable, is excluded, and transmission takes on a dramatic colouring because this new knowledge causes anxiety and destabilises. It is necessary to find compromises to avoid ruptures and be able to ignore the dangers of being unaware of a new kind of knowledge. This transmission process requires time, a period of incubation, of discussing the advantages and disadvantages of new ways of doing things. The learning economy addresses precisely this question of the speed with which new knowledge can be reproduced or again the strength with which organisational routines can reject innovation.

Value of sectoral approaches for better understanding the education sector

Along the lines of Nelson's work, one can say that the sectoral level is to be understood as a true ecological niche in which the strategies of actors are carried out within professional communities. The sectoral level appears as an appropriate level for analysis. Sectoral levels were primarily discussed in Tokyo for engineering, in Paris for health and education and in Stanford for the information technology sector. There are two articles in Part II focusing on the production, mediation and use of knowledge in the engineering (Eliasson, Schuetze) and health sectors (Bauer, Kervasdoué). Hargreaves's paper gives comparative analyses of knowledge processes in the education and health sectors whereas Kogan's and Carnoy's paper focus on education.

T*he engineering sector*

Professor Gunnar Eliasson's article justifies the sectoral approach by clearly presenting the methodological problem that consists of saying that it is not possible to understand firm strategy if one does not understand the configuration of actors and techniques. One must look again to the great economists, like Marshall, too much in advance to have been understood by his colleagues. It was Marshall who first created, in 1919, the concept of industrial district to underscore the positive eternality enjoyed by a firm when it is part of a territory, a network of relations joining actors with different goals, such as researchers, suppliers, banks, etc. In other words, such a firm is surrounded by a specific environment which will create overall productivity gains from which the firm will benefit. It is this "territory" effect that another economist as little understood at the time as Knight called, for lack of a better word, "knowledge". In brief, knowledge, through its spillovers is to be understood as a positive externality. Here lies, some 60 years earlier, the premises that constitute the theory of new knowledge developed by Romer.

Eliasson's article takes as its point of departure Marshall's work on the positive externalities of knowledge to create a new concept which he calls the "competence bloc". What is to be understood by this? Essentially that one cannot separate the strategies of private actors from those of public ones, that one cannot separate actors from the incentive mechanisms that lead them to act in a territory, that one cannot separate the incentive mechanisms from the institutions in which they are contained and which are part of national cultures. In brief, things have to be taken as a "bloc". Eliasson's thinking lies along the lines of what is known today as the school of institutional economists like Nelson. In this definition of competence blocs, one cannot fail to take the example of Silicon Valley, California, whose history cannot be reduced to a series of individual successes in the shadow of university campuses in a sunny climate. In his oral presentation during the Stanford seminar, William Miller, professor at the Stanford Graduate Business School and considered one of the historic figures of Silicon Valley, was able to trace the history of Silicon Valley and flesh out the concept of the competence bloc.

Hans Schuetze's paper raises the issue of the terms of the exchange between industry and universities when these are called upon to work together. Mutual expectations are a central issue here, inasmuch as the players do not want to find themselves in what game theorists have called "the prisoner's dilemma", which is bound to produce winners and losers when the cards are not on the table. What exactly does this entail? Namely that each side must predict how the other will behave when entering into a working relationship whose outcome is uncertain. To put it another way, what makes a firm want to work with university laboratories, and what makes universities want to work with industry? In a sector like engineering the answer is important, precisely because the linear model has been abandoned; the actual terms of the exchange constitute the social learning curve. Schuetze manages to demonstrate that firms are motivated for different reasons (size being a contingency factor). They may want to take a short cut and save time and money by harnessing specialist knowledge, but they may also want to develop relations with the laboratories as a means of permanently updating their own knowledge base; in other words, working with university laboratories is a way of keeping the firm on its toes and fighting the complacency that comes with routine; such firms can constantly improve their capacity to absorb information (from customers but also suppliers). As for universities, it is fair to say that the old bias against private enterprise is fading; working with firms is no longer considered taboo by research communities in Japan and France, for instance; academics are learning to work with industry (with varying degrees of success) and their contract work is of course aimed at killing two birds with one stone.

The medical sector

For the medical sector, comparisons with the engineering sector come to a halt on the sector's structure even if they have several points in common: the separation between basic and applied science exists just as much for physicists and engineers as for biologists and practising physicians. Both engineers and physicians share professional practices. In both cases, the rhythm of change differs, depending on the nature of the knowledge and what is at stake. In medical research, the race to discover a new molecule, the race to be first to publish results that will make a mark in a scientific community whose members are both competitors and colleagues, represents a significant challenge. The time frame of the research (publish or perish) is not the same as the time that the physician gives to a patient or the length of hospitalisation of the patient for the insurance company. Yet time will affect knowledge: how can the length of hospitalisation be reduced by developing new, less invasive techniques? How can the time physicians devote to administration be reduced? How can the time of getting new molecules to market be pared down? All these questions concerning shortening time spans are those of different actors with different concerns (economic, scientific, public policy).

The articles of Jeffrey Bauer and Professor Jean de Kervasdoué bring to light the cultural and national aspects of the health sectors in the United States and in France, which make the task of international comparisons difficult. If information technologies standardise the use of equipment and practices, differences clearly appear in terms of the place of the medical sector in the economy, which reflects, as in a mirror, the national framework.

Bauer's article maps precisely the stakes and resources that each actor will be concerned with in a North American framework. This map is not without consequences for the structuring of knowledge. Bauer predicts a relative decline in academic knowledge and a rise in knowledge that will more and more be produced by the pharmaceutical companies. To recall an expression of Eliasson's in his article, this would confirm the view that firms are more and more becoming technical universities which compete with the universities, previously considered as the storehouses of knowledge. Bauer speaks of the corporatisation of this sector, thereby underscoring the fact that the production and mediation of knowledge will be undertaken by large private groups (purchases of services, producers of drugs, the media) that will change the shape of the current landscape. Is this diagnosis valid only for North America?

In his article, Professor de Kervasdoué paints a very different picture, as French as the preceding one is American. France's medical community as yet takes little responsibility for the economic aspect of its activities, even if things are changing since the institutional upheavals which the sector underwent four years ago. As Professor Martine Bungener, Cermes/CNRS, remarked at the Paris seminar, the French medical community still implicitly acts as if health expenditures are unlimited and it has no need to be accountable for the efficacy of its activity. Teaching programmes for future French physicians still give little attention to economic and legal constraints. Bodies of knowledge about human biology, public health policy and the economy of health are in fact little interlinked.

Kervasdoué's article offers a point of view which reflects different experiences in the medical sector: that of a policy maker as former head of hospitals at the French Ministry of Health, that of director of a firm and of a consultant working for the actors in the medical system and finally that of the Chair of Health Economics at the *Conservatoire National des Arts et Métiers*. This background, which is unusual enough to be emphasised, explains the tone of an article that discusses the impact of new information technologies on the behaviour of the actors in the medical system. From all three perspectives, one finds the same push to codify practices that have not been stabilised, which is precisely the goal of expert systems in the area of engineering. This rise in standardisation can be seen in the establishment of measurement mechanisms which are designed to evaluate the activity of the medical profession not only quantitatively, but also qualitatively. In the medical sector, the codification of knowledge is changing professional practice.

The education sector

In the education sector, the sums involved and the breadth of the sector, along with that of the health sector, are considerable judging by their weight in the GNP of OECD countries and the labour market. There is also the weight of a profession (physicians, teachers) that have been able to develop a position with respect to the changes they perceive, particularly technical changes. For example, in terms of the new information technologies, there is no lack of arguments to underscore – positively or negatively – their consequences for the work of the teaching profession.

During the Paris seminar, the heterogeneous nature of the knowledge base of the education sector was emphasised. For example, the capacity of the education sector to produce new knowledge about the act of teaching and about know-how is reduced. The demand for new knowledge comes instead from the political authorities who are increasingly concerned and ask questions about both efficiency and efficacy. Given the weight of expenditures on education in GNP, the political authorities seek to evaluate the performance of education systems and to compare schools' performances. They ask questions about the relation between initial education and employment.

Three articles, each from a different perspective, present the debates taking place in the education sector.

Maurice Kogan's (Brunel University, United Kingdom) article addresses the questions raised by the political authorities by focusing more specifically on the higher education sector. The article comes to two clear conclusions: first, the importance of understanding how the various actors in the education system manipulate to their advantage the resources at their disposal. The second concerns the difficult relations between education researchers and users of the research results. A reading of Kogan's article suggests that political scientist Charles Lindbaum's bitter remark about public policy, "many suppliers and users of social sciences are dissatisfied, the former because they are not listened to, the latter because they do not hear much they want to listen to" still seems to have currency today, although it was made 40 years ago. The "art of muddling through" is still practised. Decision makers complain that research results are not usable or else much too obvious (a mountain giving birth to a mouse) or again of insufficient quality. Or they complain about the inability of researchers to enter into fruitful relations. Of course, on the other side, education researchers complain about the inability of decision makers to listen or their tendency to hear only what they want to hear. They also note that reports are not read and that no good questions are asked. Most often, the education researcher is a ventriloquist, that is to say he/she asks the questions which he/she has decided to answer. The situation is very different from that of the medical researcher or the engineer who starts from a given problem, which has often been forcefully raised by society or by pressure groups of users or clients.

The article of Professor Martin Carnoy of Stanford University indirectly provides answers to this dilemma. As an economist of education, he presents cases which show the relations between knowledge and action. The second case described in the article offers a very good illustration. The research result that states that class size does not explain school performance unless class size is very small is a "disturbing" result for decision makers in that it is counter-intuitive. Research results are used if they agree with common sense. Otherwise, they may appear politically dangerous and risk being ignored. Compared to the medical sector, the difference with respect to the legitimacy of research results is clear. There is no such thing as a socially acceptable result concerning breast cancer, whereas there is for a country's illiteracy rate. On another front, the relation between lung cancer and smoking or the relation between class size and school performance are far from neutral subjects. These research results strongly encourage the relevant actors (teachers' unions, teachers, producers of tobacco, cigarette manufacturers) to modify their practices.

Finally, Professor David Hargreaves compares, precisely and systematically, the knowledge bases of the medical and teaching professions. He chooses to speak about professions, rather than tasks or activities. In fact, his focus is on the service professionals deliver. Both doctors and schoolteachers (he does not discussion higher education) have to set up problems (diagnosis) and solve them (treatment). Hargreaves shows very clearly that school teachers are more isolated than doctors for setting up these relationships with their "clients". Schools do not as yet have an explicit set of methodological tools for diagnosis and treatment, making the entry of novices into the classroom more difficult; they learn by trial and error, relying on their own experience or on experienced teachers ready to give an hand as mentors. This is the way to capture the tacit knowledge of those who know more and are eager to share their practices. Novices (in medicine or education) enter the community of practitioners with greater or lesser difficulty, depending on whether they have to take a pragmatic approach (the job cannot be taught) or a scientific approach (the job can be taught). Finally, Hargreaves pleads strongly for a generic model of the professional knowledge base.

For a new generation of indicators

Professor Dominique Foray's (Dauphine University, France) article served as a basis of discussion for the Washington seminar organised in collaboration with the National Science Foundation. In some respects, this seminar constituted an extension of the discussions organised by CERI over 18 months on the place of knowledge in the OECD economies. The seminar brought together statistical experts and economists who work primarily on the relation between technology and society. The participants agreed that the place of knowledge in the economy is not new: there is nothing new under the sun, remarked Professor Paul David in his presentation, although he emphasised that what is new in the economy is the accelerating rate of change. To address the problem of measuring knowledge, he proposed a mnemonic device involving three "A's": accumulation, access, attention. David underscored the need to distinguish the conditions under which knowledge is accumulated, the conditions of access and the conditions of attention.

The measurement of the accumulation of knowledge comes back, as Foray points out in his article, to input indicators. Today, there are solid databases on development expenditures in research and development. These databases are managed, and collection of data takes place on the basis of a negotiated classification so as to make international comparisons possible. There are also output indicators in the form of patent applications, even if comparison is made difficult by the absence of a standard definition of what is to be understand by a patent at country level. Foray shows in his article that there is a healthy indicator industry, judging by the refinements being made to ever more sophisticated measurement instruments. The question posed during the Washington seminar was, however, that of the pertinence of these indicators in terms of their capacity to reflect what is now called a learning economy. This learning goes well beyond research and development departments, and indicators of input and output alone cannot, on their own, account for the variety of sources of learning.

It would be far more ambitious and difficult to construct indicators that would measure accessibility to knowledge and the way in which knowledge receives attention from decision makers and potential users. At the Washington seminar, it was noted that a survey by the American federal government revealed that 400 scientific papers out of 20 000 scientific articles, or 2% of the total, were considered to have potentially practical applications. For the medical sector alone, the figure was 3%. What is needed here is to build indicators that would account precisely for the way in which knowledge is shared among actors. This mediation takes place through organisational and institutional arrangement and remains to be described. Foray proposes to build a taxonomy of learning and proposes a new generation of indicators which would account for the learning dynamics of these economies.

The discussion initiated by Foray's paper led finally to a number of points of agreement. First, it was confirmed that the sectoral approach is an appropriate way to address the problem of measurement. This new generation of indicators should be tested on concrete cases, as for example by measuring the intensity of the relation between university and industry. With respect to the education sector, Professor Anne Carter, Brandeis University, stated that it was necessary not to rush into applying an economic model too simply to the education sector. Director Seamus Hegarty, National Foundation for Educational Research, United Kingdom, reinforced this point in another way. As an education specialist, he warned economists not to act like Procrustes, the carpenter who wanted to make people, whose size did not correspond to the bed that he had already built, fit that bed "at any price".

To guard against the ever-present risk of forcing observations to fit into indicators that already exist, the participants considered the possibility of creating measures as a sort of learning process, what would in systemic language be called "baby systems", that is, systems that would be built through trial and error. Bringing together experts on "how to measure production and use of knowledge in a sector like education" is already, in itself, a change at the level of the professional community. The way of measuring is perhaps more important than the figures finally obtained. In sum, it is a question of putting letters before figures. As the Spanish poet Antonio Machado put it, "se hace el camino al andar", the walker creates his own path, in other words, the participants in the Washington seminar emphasised the fact that construction of the indicators, necessarily taking different disciplinary approaches, is perhaps more important than the final result. The construction phase becomes a learning process about the pertinence of descriptors. One needs to imagine Procrustes having discussions with potential clients so that he can make a bed to fit their dimensions.

KNOWLEDGE AND INNOVATION SYSTEMS

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Introduction

Modern humans possess an astounding amount of effective "know how", technique and knowledge that allows us to do things that early humans, or humans a century ago, or a quarter-century ago, could only dream of doing. In this essay I reflect on the nature of human "knowledge and innovation systems". (See Nelson and Nelson, 1999, for an essay along the same line that draws more intensively from the literature on cognitive science.) My discussion will be divided into three parts.

First, it seems important to try to get a grip on the nature of human know how. What are its aspects, and how is it organised? Where is it "located" and how is it applied? I shall argue that human know is extremely variegated and divided, and stored in different places and forms. Much of it is of the form that often is thought of as engineering. However, much is embodied in particular human skill. And an important part of knows how is knowing how to tap into, organise, and manage what is known.

Second, there is the basic question of how humans achieved the tremendously broad and effective body of know-how that we have achieved. I (in accord with many other scholars of technological advance) will propose that cumulative innovation must be understood as a process of "cultural" learning or evolution. That cultural evolutionary process, in turn, involves the coevolution of technique and knowledge.

Third if one reflects on the matter, it is clear that our know-how in fact is extremely uneven. Some areas of human know how today are extraordinarily powerful largely as a result of relatively recent developments; consider "information technologies". On the other hand, it is not clear that our ability to educate children has advanced very much over the last century, or five centuries. And managerial know how has not improved much over the years. Our cultural learning or evolution system appears to work much better in certain arenas than in others. Why?

In the concluding section I will propose a tentative answer, and explore some of the consequences, if I am correct.

The nature of human know-how

Different groups of scholars have looked at the nature of human know-how from quite different angles. Cognitive scientists, and psychologists studying learning and memory, have focused on know-how at the level of individual humans (see *e.g.* Newell and Simon, 1972; and Dreyfus and Dreyfus, 1986). Some business historians, and scholars of business organisation and strategy, have concerned themselves with organisational capabilities, and in particular with what business firms know how to do (Chandler, 1990; Nelson and Winter, 1982; Teece, Pisano and Shuen, 1997). Scholars of technological advance have concerned themselves with the nature of know-how at the level of technological communities. A number of recent studies of biotechnology, and others of Silicon Valley, have treated know-how as residing in a network (Powell, Koput, and Smith-Doerr, 1996), or in a region (Saxanian, 1994). A considerable portion of the rhetoric associated with advocacy of technology policy sees technological and other kinds of know-how as residing somehow in the nation-state.

Perhaps each of these points of view is partly correct. It is important to recognise a variety of different kinds or aspects of know-how.

In the first place, and putting aside for the moment the question of the "locus" of know how, the nature of know how is itself complex, involving both a body of practice, and a body of understanding. Different scholars have stressed different aspects. For example, within cognitive science, those whose orientation is to artificial intelligence have tended to focus on human understanding, seeing purposive human action taking – practice – as basically determined by the logical information processing apparatus, and the learned facts and relationships bearing on the action context, presumed possessed by the human actor (Newell and Simon, 1972). In contrast, another group of cognitive scientists sees effective human action in a context as the result of trial and feedback learning that has shaped that action, with little or no use of logic or broader understanding involved either in effective action taking or its learning (Dreyfus and Dreyfus, 1986).

In turn, both practice and understanding come in various sizes, and shapes, and effective combinations.

Thus, consider the collection of skilled practices involved in performing heart surgery. The surgeon has command over a certain body of practice. So does the anaesthesiologist. To a considerable extent these bodies of practice are different. On the other hand, each knows "about" the skills of the other. In the performance of an operation there will be a number of assistants involved who have command over certain skills. Some, but not all, of what they do could be done by the surgeon or the anaesthesiologist, but it is far less costly to delegate relatively simple tasks to less highly trained and paid people. In general the surgeon serves as orchestra director, as well as key player in the operation. However, all the players know at least the broad outlines of the overall operation, and the details of their own roles in it. In general a successful operation requires that all of the roles be performed effectively, and in effective tune with each other.

In the case of heart surgery, like in most modern technologies, much of the technique is embodied in materials, apparatus, and other artefacts. The anaesthesiologist works with various substances that have been found to be effective, with pieces of apparatus that deliver those substances, and with a variety of dials and other measuring instruments that enable him or her to monitor what is going on. And the physician, of course, also works with a complex of materials and instruments.

Behind the surgeon's command of skilled practice, and the anaesthesiologist's, lies a broader body of understanding involving the human body, and the various substances and instruments being employed in the operation. When things are going routinely, that broader body of understanding never may be invoked consciously. But that body of understanding may play a very important role in holding skilled performance in place, being invoked unconsciously to prevent deviations that could undermine effectiveness or court trouble. And from time to time, in particular when something is seen or occurs that is not quite what is expected, conscious thinking tapping that body of understanding may be essential to effective performance.

Ever since Michael Polanyi (1958) pointed it out, scholars have recognised that some of human know-how is "articulated, "in the sense that it can be described and communicated in some form of language, while other aspects are "tacit". Thus a good portion of the skilled technique in the minds of the surgeon and the anaesthesiologist can control the work of their fingers, but may not be easily explainable in words or other symbols to others, even other physicians, who however perhaps can learn by watching and trying to imitate. But other parts of their relevant know how can be expressed in words in a way that can be understood, at least by other professionals with the same background of tacit knowledge.

These articulated parts of know how often are written up in texts and treatises. Studying these may be an essential, if not sufficient; part of the way that pre-meds become doctors. And experienced doctors will go to the journals to find out what is new, and sometimes to refresh their own knowledge. Like extant equipment and materials, texts and libraries provide storage for know how outside of individual human minds.

While it seems natural to associate "tacit" with the practice aspect of know-how, and articulated with the understanding aspect, I do not think the mapping is all that neat. Thus while it is clear that much of "technique" is tacit, a cake recipe, or a blueprint, is all "technique", but to a considerable extent is laid out and articulated on paper. Also, a considerable amount of technique is embodied in the artefacts used, and while the anaesthesiologist may not be able to explain just how his machine works, he or she almost certainly can identify it by name and explain its use in a way that would enable another doctor to obtain and use it. On the other hand, the surgeon may see and understand that something is not going quite right with the operation, and not be able to explain in words just what he or she sees, or why that seems to signal trouble.

But language, and the ability to lay out know how in language, clearly is very important in making know how broadly available – an element of culture, as it were. The know how of the surgeon and the anaesthesiologist is cultural in the sense that much of what they know also is known by other surgeons and physicians, who have gone through similar training programmes, use the same equipment, read the same journals, attend the same conferences. There are various mechanisms that facilitate, or even force, sharing of information among professionals. I do not mean to play down here the tacit aspects of learned skills, which may be behind very great differences in effective performance, or the efforts of some professionals to keep certain aspects of their technique and understanding privy. But a striking aspect of most broadly important bodies of technique and understanding is that they are broadly shared.

On the other hand, it is clear that the overall know-how needed to perform complex tasks often is very divided. Consider the separate bodies of practice and understanding possessed by the surgeon, and the anaesthesiologist. In turn the anaesthesiologist may know how to make his equipment work, but little about how to produce or design that equipment. People at the company that sold the machine may know those things, but no one at that company may know all of it. Reflect on whether anybody, or any small group, at Boeing Aircraft Company "knows how" to produce, or design, a modern aircraft.

It is clear that this division of knows how has always been a fact of life, and for that reason (among others) much of "doing" always has been a co-operative endeavour. But it would appear that as human know how has advanced; it has become increasingly divided and specialised. The Wright brothers designed their complete aircraft themselves, using of course a lot of materials and equipment that had been designed and produced by others. Aircraft design today involves large number of engineers designing individual parts, subject to a set of constraints that aim to assure that the parts fit and work together.

Because overall know-how is divided and widely distributed among different individuals and groups, to be effective know-how needs to be brought together and co-ordinated. For that reason, an extremely important part of know-how is knowledge of the elements that are needed, and how to co-ordinate, and manage their combined operation.

In another paper, I used the term "social" technologies to describe the latter kind of know how, and differentiated social technologies from physical technologies, a term I used to denote what engineers generally mean by technology (Nelson and Sampat, 1999). Under the standard conception, physical technologies are recipe or blueprint-like, characterising what is to be done, but do not speak to how the work is to be divided and co-ordinated. In contrast, what I call social technologies are associated with effective structures of division of labour, and procedures for task co-ordination, and management.

As with practice and understanding, and tacit and articulated know-how, the physical and social aspects of technologies often are intimately intertwined. Consider the famous Ford mass-production line for Model T cars, or the Toyota method of "lean manufacture". These involve both a set of sequenced physical actions taken by the parties to the process, and a division of labour and a co-ordinating mechanism so that the actions taken by the particular parties ultimately add up to a finished automobile. Or reflect on the heart surgery example that I gave at the start of this section. Again, one sees a complex mix of physical technologies involved, employed by a team in which each member must do assigned tasks in harmony with what others are doing.

This complex mixture of understanding and practice, of articulated and tacit know how, of physical and social technologies, that I argue is involved in much of productive human activity, may define a "knowledge system", to use a term that recently has become fashionable, but a system that often is very hard to visualise coherently, much less characterise verbally or in other symbols. Louis Bucciarelli (1994) has arrived at a similar conception in his analysis of what it means to know "how your telephone works". Various parts of the relevant know how are located in different kinds of places, and stored in different forms. Some is related to how to do it, some with why doing it that way works. Some is possessed by individuals, some by organisations; some is in networks or communities. Some is held in trained fingers, some in trained minds, some in texts, and some in materials and machines.

The system has been brought into place, and develops further, through the actions of many individuals and organisations that have particular objectives in mind. However, the overall system cannot be regarded meaningfully as having been planned. Rather, our know how systems need to be understood as having evolved, in a sense I will elaborate in the following section.

The nature of technological advance

Scholars of technological advance, from a wide variety of disciplines, have argued that technological advance proceeds through an evolutionary process (see for example Basalla, 1988; Mokyr, 1990; Petroski, 1992; Nelson and Winter, 1982). The process is evolutionary in the sense that at any time there generally are a wide variety of efforts going on to advance of technology, which to some extent are in competition with each other, as well as with prevailing practice. The winners and losers in this competition are determined through an ex-post selection process.

Following the path mapped out by Donald Campbell (1965) in his great work on evolutionary epistemology, Professor Walter Vincenti has argued that attempts to solve technological problems, to advance of technology, are to some extent "blind". At first thought that term might seem to connote a process in which attempts at invention are largely random, with little in the way of guidance from the inventor's understanding of the technology in general and the problem being addressed. The conception that efforts at invention are blind then would seem to be in sharp opposition to the arguments of those who propose that to a considerable extent modern inventing is "science-based" and heavily exploits scientific understanding.

In fact Vincenti's view of inventing and technological problem solving in aviation (the subject of his study) involves professional scientific knowledge and technique in an essential way. He provides an extensive catalogue of the kinds of complex knowledge that modern aeronautical engineers, and discusses in detail how this body of knowledge guides their efforts at design. However, he, and other scholars who propose that technological advance is an evolutionary process, argues (and provides the documentation for the argument) that efforts of inventing and technological problem-solving almost always reach beyond the range of options that is perfectly understood, and in that sense are somewhat "blind". Therefore, to a considerable extent what works and what does not, and what works better than what must be learned through actual experience.

Most scholars of technological advance also are united by their insistence that the process needs to be understood as "cultural" in the following very important sense. Technological advance in virtually all fields is a "cumulative process" where today's advances provide both starting places and building blocks, and challenges, for tomorrow's attempts to advance the technology. What is learned today influences what can be achieved tomorrow. And in almost all fields, a number of different actors contribute over time to this cumulative process. At each stage, those who are attempting to advance the technology are standing on "the shoulders of giants" or more accurately, on the top of a large body of already achieved technique and understanding that has been developed by a large number of predecessors.

I have stressed that technology involves a body of technique or practice, and a body of understanding or knowledge. In the process of technological advance, both evolve. Or, I would propose more specifically that technique and understanding coevolve. Technique and understanding are linked to each other. A particular advance – a new product or process – generally brings with it a wider body of new understanding that includes, but transcends, the particulars of the new technique. A new understanding, earned through this route, or through efforts more directly aimed to advance understanding, in turn provides clues and opportunities for the further advance of technique.

What leads and what lags in this process? A body of conventional wisdom has it that, at least in the modern world, knowledge in the form of new science leads, and the development of new technique follows. Thus, Maxwell's theory made possible and stimulated the development of practical radio communication. The development of scientific understanding of the ring structure or organic molecules enabled the development of the modern dyestuffs industry. Advances in molecular biology permitted the rise of the modern biotechnology industry.

But in many other instances, the advance in technique leads and the development of understanding follow. The most cited case probably is Sadi Carnot's articulation of the laws of thermodynamics which he developed in research initially stimulated by his interest in understanding how steam engines worked. The basic advance in understanding of semiconductors put forth by William Shockley in his *Holes and Electrons in Semiconductors* (1950) reflected the theory he developed in order to explain the semiconductor-amplifying device he and his colleagues at Bell Laboratories more or less stumbled upon.

For a long time there has been at least a rough division of labours between those that employ a technology, and those that work to advance that technology. However, it would appear that the sharpness of this divide has increased over the years.

The conventional image of the inventor prior to, say, 1800 was that of a person intimately familiar with a technology, generally working with it himself, and tinkering to improve it. However, there always has been something of a division of labour between the operators of the technology, and those who invented in the field. At the least, the latter were a very small sub set of the former. And there always have been inventors who could not be considered to be practitioners. Consider, for example, Thomas Edison. However, with the rise in the power of modern science to illuminate technology, and to facilitate technological advance, the separation clearly became sharper. That separation was institutionalised in the growth of industrial research and development laboratories, whose personnel specialised in "inventing".

Since the days of Francis Bacon, the pursuit of understanding and the pursuit of effective technology have been linked, at least in the minds of the philosophers who advocated both of these activities? However there always has been a rough, and sometimes a sharp, division of labour, and this division probably also has widened in the modern world. On the one hand, while in some areas of technology there is considerable overlap, in most there is a division of labour between industrial and university research. And in many cases there are relatively clear lines between a science, like physics, and a field of technological inquiry, like aeronautical engineering.

But there continues to be considerable overlap of the activities. Thus William Shockley was both technological inventor and theoretical physicist. And in the applied sciences and engineering disciplines the activities are intertwined tightly. This is so even in academia.

The notion that academic science proceeds with no consideration of practical applications is, by and large, a myth. Indeed, at the present time, the lion's share of research going on in American universities is in fields with names like "material science", computer science, electrical engineering, pathology, etc. In today's world science is useful to inventing not so much because of accident, but because many fields of modern science are designed to help clear the path for technological progress. In a recent survey, industrial R&D executives were asked to identify the fields of academic science that most contributed to the successes of R&D, and they strongly tended to list fields of the sort mentioned above, as contrasted with, say physics or mathematics. On the other hand, it is clear that fields like material science and computer science draw extensively from physics, and mathematics.

For me at least, a striking characteristic of fields where technological advance has been rapid is that all of them seem to have closely connected and powerful sciences or engineering disciplines. These bodies of scientific knowledge serve, first, to enlarge and extend the area beyond existing practice that an inventor or problem solver can see relatively clearly, and hence go into without being completely "blind". That is, strong science provides guidance regarding what particular paths are likely to lead to solutions or improvements, and which are likely to be dead ends. In technologies supported by strong science, an inventor often can see a good distance down the road.

Second, the sciences, and the engineering disciplines in particular, provide powerful ways of experimenting and testing new departures, so that a person who commands these can see relatively quickly and cheaply if they work, or are promising, or problematic. Thus pilot plants play a key role in efforts to develop new chemical process technology. Wind tunnels used to play a similar role in aircraft design. Where scientific and engineering knowledge is strong, these days one can explore and test by building computer models. More generally, strong scientific knowledge not only enables inventors to see promising paths, but also to assess the real promise of the path in a timely fashion.

Why has achievement been so unbalanced? Some speculations

The discussion above sets the stage for reflection on why the advance of human know how has been so uneven, spectacular in areas like information and communications technology, remarkable in dealing with certain kinds of human illness, very limited in other areas, for example education, or avoiding wars. I have proposed that there are two key factors that enable rapid technological advance in a field. One is a strong body of understanding that enables efforts to advance a technology to reach significantly beyond the current state of the art before getting into areas where probing is completely blind. The other is ability to get relatively sharp and quick feedback from efforts to advance the art regarding whether the departure is a success, or at least promising, or not, preferably on the basis of probes that are less expensive and time consuming than full scale trial.

I have argued that both tend to be enabled by a strong science that illuminates the technology. However, here I want to focus on them as variables in their own right, and to look at the causal arrow the other way. In particular, I want to propose that the ability to conceive and carry out well defined and controlled experimental probes of possible ways to improve technological performance, and to get sharp quick and reliable feedback on the results, contributes importantly to the ability of a science to develop that really illuminates that technology.

Yes, I recognise, indeed I highlighted earlier, that some technologies in effect are born out of prior scientific discovery; thus the enabling scientific understanding was already "there". The electrical and organic chemical product technologies are good cases in point. But after these technologies emerged, they themselves began to pose scientific problems and puzzles. That early vacuum tubes and transistors could be experimented with was very important to the development of new science that enabled their further development.

Of particular importance, the development of the technologies led to the creation of new fields of applications oriented sciences. Electrical and chemical engineering were fields of research as well as teaching that came into existence as the industries using the technologies grew in importance. The invention and development of the transistor and integrated circuits provided strong intellectual stimulation (and a reason for financial support) to the field of solid state physics, and led to the rapid development of material science.

These new scientific fields rapidly enriched and improved their theoretical bases. But from the beginnings they have been very experiment oriented. And much of the experimenting has involved aspects of the technologies that provide the reason for the field's support. In turn, advances in the technologies have provided puzzles and challenges for the sciences.

Do I overstate the role of experimentation in the development of science? I do recognise that astronomy, now cosmology, is not strictly an experimental science. However, given its intellectual base in physics, it has been possible to both draw on and focus experimental physical research which probes at the fundamental theoretical conceptions of astronomy and cosmology. And the ability to make precise empirical observations of the sort needed to rigorously test evolving cosmological theory has enabled that science to proceed almost as if it were experimental. In some cases non-experimental data can provide the basis for a strong science. But most of the strong fields of empirical science that have been developed have involved experimentation in an essential way. And I believe that this is very much the case with sciences that illuminate technologies.

Consider some of the implications, if this argument is broadly correct. First, it is a poor bet, and likely waste of money, to pour resources into advancing practice in a field, if understanding there is weak. There is little then to guide efforts to develop technology that will perform significantly better than prevailing practice. And information as to whether or not the new departures are effective may be slow in coming and inconclusive. This argument of course is not new. Consider the debate several decades ago about the wastefulness of launching a "war on cancer".

But second, the argument points to the major difficulties and the long time period that may be required for the success of a strategy of pouring resources into an effort to develop a science to enable the more rapid advance of technologies where advance has been painfully slow, and to the chance of complete failure of the effort. More, it suggests that the achievement of a science that illuminates a technology may depend on transforming the technology so that the technology becomes more amenable to scientific inquiry.

I noted earlier that in fields where technological advance has been impressive, most of the inventing goes on "off line", as it were, in a specialised R&D activity. To do R&D effectively to advance a technology, it is necessary to isolate the technology from its surroundings so that it can be experimented with. It helps a lot if it can be divided up into components or aspects that can be manipulated independently and in such a way that the effect of variation on overall performance can be assessed. A certain simplicity of the causal structure, or at least the absence of strong and complex interaction effects between the variables that can be manipulated, and between these and those that cannot be controlled, is virtually a requirement for learning to be possible through this route. Further, the variations being explored must be reproducible, so that the experiment or test can be replicated, and many parties can be involved in efforts to advance the technology, a condition I argued earlier seems to be essential if progress is to be cumulative. And the replicability condition is essential, of course, if what is learned or created in R&D is to be usable in practice.

My point is that not only are these characteristics conducive, probably necessary, if a technology is to be advanced cumulatively and rapidly through experimental trial and feedback. They may be necessary, and certainly are conducive, for a body of science to grow up that supports efforts to advance know how in an area. Artefacts, materials, machines, tend to have these characteristics. So do well articulated techniques more generally. In contrast, if major elements of the technology are social and tacit, technological progress may be very difficult to achieve.

Consider a highly relevant case that illustrates, I believe, several of the points I have just made the efforts to develop more effective school educational practices (see Murnane and Nelson, 1984, Hegarty, 1999.) It is well known that learning in school is not independent of what is going on in a child's life outside of school. With the exception of computers, which have yet to be widely employed, the artefacts involved in schooling are relatively simple, and, with the exception of textbooks, themselves contain little of the relevant practice. Education as it currently is practised largely involves a set of quite tacit techniques used by individual teachers, operating in a classroom where many different students are involved in the learning process; hence a considerable amount of classroom organisation and management is required of the teacher.

The tacitness of teaching techniques, and the sensitivity of the techniques that work in the classroom to the particularities of individual children and to how they interact, is associated with limits on the ability "teach teaching", except through a process that involves some observation by apprentice teachers of teachers who are regarded as skilful, and also with considerable variation in teachers regarding what they actually do. If that actual variation could be sharply described, and the effects of different variants were independent of context conditions that cannot be controlled, or even sharply described, then that variation itself could be a source of learning and improvement for the teaching profession as a whole. But these conditions do not seem to hold in education.

These problems are reflected in the limited ability to conduct educational experiments, the results of which provide reliable guides to how to improve educational practice in real world settings. For many years such experimentation has been high on the agenda of scientifically oriented Schools of Education. But consistently the record has been that what is reported to work in a lab school or in another chosen testing locus has been hard to duplicate outside of the locus of the original research. Part of the problem clearly has been that it is impossible to describe what the experimental treatment was with sufficient precision and detail so that one could know whether one was replicating it or not. Part of the problem also surely is that the context conditions that enabled a particular treatment to work were not fully known, and not necessarily in existence in other places.

The same problem holds regarding larger statistical studies that collect and analyse data from a number of different schools or classes or modes of teaching. It is not that statistical studies do not identify important correlates of good educational performance. One important correlate is the education and income of a student's parents. Another is the training and experience of a student's teacher. But the former provides no information as to how to improve the performance of schools, given the backgrounds of the students. And while the latter does provide guidance to schools regarding the kind of teachers they ought to hire and about the importance of encouraging promising teachers to stay in the system, it tells very little directly about the educational practices that work best.

One might observe that part of the problem is that the science motivating or being tapped in such studies isn't rigorous enough to provide adequate guidance and interpretation. It has been argued that the development of better educational practice needs to draw more on fields like cognitive science. In fact, research in cognitive psychology has provided a certain amount of understanding about how children learn. However, that illumination is not easily translated into good guides regarding how teachers ought to teach. The practice is simply too far removed from the tight experimental conditions that have enabled the development of the science, but also constrained it to very stylised contexts.

This clearly stands in sharp contrast with other arenas of human know how, like information processing and communication, or various areas of medical care. Since both education and medical care are activities focussed on helping individuals, and the recipient of the treatment is a vital element of the process of learning or healing, perhaps the contrast here is particularly worth exploring.

Most of the significant advances in medical care have occurred over the past one hundred and fifty years, and have been associated with a tremendous increase in scientific understanding of human illness of various kinds, and of the effects of various treatments. The basic mechanisms in question are biological, and beneath the biology is a lot of chemistry and some physics, all strong fields of science. Animals in many cases provide convenient models of humans, in circumstances where lab chemistry does not illuminate what is going on.

In general the improvements in performance of medical care have occurred in areas where understanding has become strong, but this is not always the case. In many cases we have learned that certain medical treatments work (like aspirin on headaches, and as a means to prevent certain kinds of heart problems) but (in this case until recently) have had little understanding of just why. But we have been able to learn that aspirin works, and make use of that knowledge in the practice of medicine, because aspirin is a well identifiable substance, "taking aspirin" a routine that can be well enough described so that people instructed to do it can do it, and the effects of aspirin are in most cases not greatly influenced by variables that can vary a lot and not be controlled.

But as the aspirin example indicates, the treatments that we have learned work well have tended to be very well defined; indeed most of them are materials or other artefacts (glasses) that we have learned (often scientifically) to characterise precisely. And by and large their effects are not greatly influenced by factors from which they cannot be shielded (but consider the warnings on medicines regarding what not to take at the same time). Thus we are able to control and calibrate the treatment, and are able to learn from variation, either accidental or deliberate.

On the other hand, where treatment can not be specified in terms of pills or other physical substances, or the effects of treatment cannot be isolated from those of other variables and actions (as in treatment of obesity), or where understanding is weak and animal tests do not provide much information (as in study of the effects of diet on the incidence of cancer) medical R&D does not demonstrate much power. Here the situation is not very different, it seems to me, than in R&D on education.

There of course has been a long standing argument between educators who have advocated bringing more tightly controlled and explicit routine to the education process, and those who have resisted this strongly saying that this hinders tailoring education to the particular needs and capabilities of individual students. Also, education is not something that can be forced down throats, but requires active participation on the part of the students. These arguments may be compelling. However, it also is quite possible that leaving education know how and technique largely tacit and social is a serious obstacle to the cumulative advance of know how.

Social technologies and the evolution on know-how

Are social and tacit technologies, and perhaps especially technologies that are both social and tacit, the exceptions that fall outside of the remarkable abilities human societies have shown to advance their practical know-how? The discussion above has been concerned only with education explicitly. But the elements that seem to make progress difficult there would seem to hold as well for prevention of crime, or teen age pregnancies, or managing the medical care system, or the Internet. Interestingly, the two last examples are of cases where the underlying physical technologies have become very powerful, but the social technologies needed to manage them are not very effective.

Recently several economists, especially Arora and Gambardella (1994), Dasgupta and David (1994), Cowan and Foray (1997), have argued that whether a technique is tacit or articulated and codified depends to a good extent on the magnitude and skill of the efforts to codify it. While it is not plausible that even a major effort could fully codify the skills of an expert surgeon, or the details that make for a very productive semiconductor production operation, the argument seems right, at least up to a point. Perhaps the same argument is valid regarding social technologies. The problem with advancing social technologies is that there are strong constraints associated with the wills and beliefs of the people who's actions must be co-ordinated or managed. Perhaps the course to greater effectiveness is to get rid of these constraints.

Indeed in many arenas exactly this has been done. Taylorism routinized and made explicit the jobs that workers did in manufacturing technology, and machinery and later more general automation transformed much of what had been a social technology of management and control into physical technology. Once this was done, it was possible to experiment with new designs for machines and automated co-ordination mechanisms, and make real progress on the management and co-ordination problem.

Can we do the same thing with drugs to control individuals who are judged likely to commit crimes? Can birth control pills be mandated for all teenagers?

As with education, there clearly are limits on our willingness to routinize and mechanise many other areas of human activity, for the sake of better control, and the ability to make faster progress. A *Brave New World* is not all that attractive.

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THE LEARNING ECONOMY: SOME IMPLICATIONS FOR THE KNOWLEDGE BASE OF HEALTH AND EDUCATION SYSTEMS

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Introduction

It is important for several reasons to analyse the characteristics of knowledge creation and the knowledge base in specific fields of social practice such as health and education. The mode of knowledge creation reflects habits and traditions specific to a field, and the mode which characterises a specific field may vary across regions and nations. To challenge old ways of learning and of distributing and using knowledge is a fruitful exercise, while comparing different modes may promote the development of new modes of learning which are more satisfactory in a socio-economic perspective.

It is also necessary to take account of the systemic character of knowledge production. The flourishing literature on innovation and technological systems takes as its starting point the fact that innovation and knowledge creation are interactive processes in which different agents and organisations exchange information and co-operate to produce new knowledge (Lundvall, 1992; Nelson, 1993; Edquist, 1997). Relationships among the agents and linkages among organisations will often be long-term. Their interaction will be affected not only by formal rules, such as regulations and laws, but also by informal rules, norms and habits specific to the field of knowledge or to the local context. To focus on single variables and/or on individual organisations without taking account of these interdependencies would lead to misleading conclusions.

It is also important to understand how specific sub-systems – here the health and education sectors – are positioned in the wider socio-economic context and what the broader system's major trends are. These sectors do not function in a vacuum; they gain their legitimacy and functionality in their interaction with the overall system.

This paper gives one characterisation of the wider context, especially its economic dimensions and spells out some tentative implications for the mode of knowledge creation in these two sectors. Its main proposition is that the present situation may be viewed as a "learning economy". From this perspective, it is argued that the health and education sectors will experience fundamental changes in their functions and predominant modes of knowledge creation in the coming years. They will be forced to take on a stronger social responsibility in order to counter the tendency towards social polarisation that is inherent in the learning economy, and they will play a key role in the reproduction of "social capital". The health system in particular, even where it remains part of the public sector, will increasingly be exposed to market forces and profit incentives. While such developments will stimulate agents to introduce incremental innovations and organisational change, they may, if not carefully monitored and regulated, undermine the sub-system's credibility and, indirectly, its efficiency. Appropriate public regulations and broad ethical consensus about what is right and what is wrong may be the most pressing issues in order to safeguard adequate and credible knowledge creation in both sectors.

Finally, some methodological issues are raised. It is argued that the two sub-systems should be broadly defined when analysing their knowledge base. The need to distinguish between and understand better the relationships between tacit and codified knowledge is also addressed. Explicitly redefining different modes of learning in these terms may be central to a renewal of the modes of knowledge creation.

The learning economy

Learning and the rapidity of change

It is increasingly recognised that knowledge is at the core of economic development. This is reflected in the terms "knowledge-based" or "knowledge-intensive" economy (OECD, 1996; Foray and Lundvall, 1996). For economists accustomed to the terms "capital intensity" and "labour intensity", the concept is easy to grasp. Perhaps a better way to refer to the present situation is as a "learning economy". Knowledge has always been central to economic development, and it is not clear that the amount of economically useful knowledge has radically changed. The useful stock of knowledge is not the sum of all the knowledge created. Much knowledge has been lost in a process of creative destruction, and the last decades have been characterised by an acceleration of both creation and destruction of knowledge: information technology has made much information more easily accessible to many people, but it also has rendered many skills and competencies obsolete. What is really new is the rapidity of change; for economic success today, the possession of a specific, specialised knowledge base is less important than the ability to learn and to forget. For individuals, firms, regions and national economies, success in the current market economy requires rapid learning and forgetting (as old ways of doing things often hinder efforts to learn new ones).

Is accelerated change only a market-related tendency or has it also occurred, for instance, in academic research? There are good reasons to assume that it has. First, there is a spillover effect. More rapid change, including incremental technical innovations, will affect process technology in academia, and its interaction with the business sector will force it to adapt. Second, specific mechanisms within academia work in the same direction: being first to present a major finding can result in both honours and material recognition (directly through prizes and indirectly through the price mechanism). Today, new factors may increase this traditional competition. In most areas, several research teams (or even networks of teams) work throughout the world in parallel on the same problems, and their information technology links make the competition more transparent. The acceleration will be most obvious where the market and academic research combine, *i.e.* in scientific fields such as biotechnology.

Another important issue is whether there is a trade-off between speed and depth of research and learning. Do accelerated change and greater competition mean shallower, shorter-term results? Competition regimes that favour being first to the market and place greater emphasis on short-term financial profit will see a reallocation of resources away from long-term research and towards less ambitious short-term projects. This may partly explain the observed stagnation of R&D expenditures in the business sector. When academic science is closer to the market, the effect may be similar. Long-term, very uncertain research projects may be less attractive when colleagues in the next office are becoming rich thanks to patenting and prizes.

Finally, there is the fundamental issue that more rapid change tends to increase economic inequalities. A large and growing minority of people are excluded from regular employment or receive very low pay because they are unable to adapt their skills rapidly enough. This is the most fundamental cause of the polarisation in labour markets which appeared as a general trend in the OECD Jobs Study (OECD, 1994). As a result, the health and education sectors face new responsibilities and new challenges.

What is learnt in the learning economy?

Learning is popular these days (see, for instance, the explosion in management-oriented literature on learning organisations), although it is not always clear what kinds of processes are involved. In the present context, learning is viewed a process whose core is the acquisition of competence and skills which lead to greater success in the pursuit of one's own goals or those of one's organisation. This corresponds quite closely to what is generally meant by learning. It is also the kind of learning that is crucial to economic success. However, it differs from most definitions of learning in standard economic theory where it is either synonymous with information acquisition or treated as a black box phenomenon assumed to be reflected in productivity growth.

In order to understand the role of learning in the economy, it is useful to distinguish between different kinds of knowledge which can be defined as know-what, know-why, know-how and know-who (Lundvall and Johnson, 1994).

K*now-what* refers to knowledge about "facts". How many people live in New York, what the ingredients in pancakes are and when the battle of Waterloo took place are examples of this kind of knowledge. Here, knowledge is close to what is normally called information – it can be broken down into bits.

K*now-why* refers to knowledge about principles and laws of motion in nature, in the human mind and in society. This kind of knowledge is extremely important for technological development in certain science-based areas such as the chemical and electric/electronic industries. Access to this kind of knowledge will often make advances in technology more rapid and reduce the frequency of errors in procedures that involve trial and error.

K*now-how* refers to skills, *i.e.* the ability to do something. It may relate to the skills of production workers but it plays a key role in many other economic activities. The businessman who judges market prospects for a new product or the personnel manager who selects and trains staff use their know-how. It is misleading to characterise know-why as science-related and know-how as practical. One of the most interesting and profound analyses of the role and formation of know-how is actually about the need for skill formation among scientists (Polanyi, 1958/1978). In everyday life, when interpreting what is happening around us, we apply models of causality that have very little to do with science. Know-how is typically a kind of knowledge developed and kept within the border of the individual firm or the single research team. But as the complexity of the knowledge base increases, co-operation tends to develop. One of the most important reasons for forming industrial networks is the need for firms to share and combine elements of know-how. Similar networks may be formed between research teams and laboratories.

This is one reason why *know-who* becomes increasingly important. The general trend towards a more composite knowledge base and towards new products that typically combine many technologies, each of which has roots in several scientific disciplines, also makes it crucial to have access to many different sources of knowledge. Know-who involves information about who knows what and who knows how to do what. But it also involves the ability to co-operate and communicate with different kinds of people and experts.

Learning different kinds of knowledge

These different kinds of knowledge are mastered through different channels. While know-what and know-why can be obtained by reading books, attending lectures and accessing databases, the other two categories are rooted in practical experience and in social interaction. Know-what and know-why can more easily be codified and transferred as information. They may even be sold in the market if the proper institutional instruments are developed. This is why economic analysis tends to focus on processes of learning involving the transfer of know-what and know-why but neglects know-how and know-who.

Know-how will typically be learnt in a manner similar to apprenticeship, where the apprentice follows the master as a trustworthy authority (Polanyi, 1958/1978, pp. 53 *et passim*). The importance of know-how in the natural sciences is reflected in the fact that students' training involves field or laboratory work, so that they learn the necessary skills. In management science, the strong emphasis on case-oriented training reflects the need to simulate learning based on practical experience.

Know-who is gained in social interaction and to some extent in specialised education environments. Communities of engineers and experts maintain their relations through alumni reunions and professional societies where they can engage in information bartering with professional colleagues (Carter, 1989). Know-who also develops in day-to-day dealings with customers, sub-contractors and independent parties. One important reason why big firms engage in basic research is that it gives them access to informal networks of academic experts (Pavitt, 1991).

The analytical framework

It is well-known that the core of standard economic theory is the view that rational agents make choices between well-defined (but possibly risky) alternatives and that economic analysis focuses on the allocation of scarce resources. What is proposed here is a double shift in focus. First, learning, like innovation, can, in principle, be treated in analytical frameworks close to those of mainstream neo-classical economics. It is possible to apply the principles of rational choice to an analysis of innovation. It may be assumed, for instance, that funds are allocated to alternative R&D projects on the basis of the private rate of return while taking into account the risk that the projects will not succeed.[1] Learning may also be directly linked to the allocation problem and to the market process. While Schumpeterian entrepreneurs destabilise and create havoc with general equilibrium, the main function of Kirzner entrepreneurs is to re-establish equilibrium through a learning process. Kirzner entrepreneurs fill the void of ignorance between producers and consumers (Kirzner, 1979). This is in line with Hayek's presentation of market exchange as a learning process.

The learning economy perspective differs from the standard analytical framework in several respects. First, the foundations for making choices – technologies, preferences and institutions – are assumed to be in a process of flux; they are learnt and then forgotten as time goes by. Also, it is considered that agents are more or less skilful in taking decisions and that the learning process may enhance these skills. Second, the focus is less on allocating existing resources than on the creation of new values, products and services. In a learning economy characterised by rapid (and even accelerating) change, it would be "irrational" for individuals, firms and national systems to use all their intellectual capacity to reshuffle the resources they control, at least as long as it can be used to create new ideas and new things that can be brought to the market. Those who focus exclusively on allocation would not survive in the long run.

It follows that the neo-classical analytical framework cannot easily capture the learning economy and that there are good reasons to look for an alternative. Evolutionary economics increasingly presents itself as such an alternative. The emphasis it gives to qualitative change and its use of concepts such as variety, selection and reproduction makes it much more relevant for analysing innovation and learning. What is less attractive in the evolutionary framework is the fact that it leaves as little room for human discretion in designing institutions and structures as the neo-classical models. Normally, a combination of chance and fate determine the outcome of an evolutionary model. A major challenge for evolutionary economics is to design models which explicitly take into account the impact of social and political discourse. People do not blindly play by rules given from above; they constantly quarrel about the rules and, from time to time, they unite in order to change them.

The critical importance of tacit knowledge

In the learning economy, tacit knowledge is as important as, or even more important than, formal, codified, structured and explicit knowledge.[2] The two types are symbiotic. Although codified knowledge can be exchanged, a firm needs supporting tacit knowledge to make it operational. Nonaka and Takeuchi (1995) have convincingly demonstrated that a firm's learning efficiency critically depends on an institutional structure that facilitates a spiral-type interaction between tacit and codified knowledge.

What is tacit knowledge?

The distinction between tacit and non-tacit knowledge is not always clear, and it may be helpful to illustrate the distinction with some examples. The first is the classical one of the skilled worker/artisan who uses tools and materials to form a final product: a baker mixes flour with milk and eggs to produce pancakes. If the quality of ingredients and the process equipment were completely standardised, and the environment completely stable, this tacit knowledge could easily be transformed into a recipe non-experts could use (the knowledge could be reduced to a formula):

2 eggs + 1 cup of flour + 1 litre of milk = 5 pancakes

However, if the ingredients vary in quality and if the environment is unstable, the proportions and the process have to be adapted to obtain an excellent product. This example illustrates that the degree of complexity and the rate of change in quality and environment may determine how far tacit knowledge can be transformed into transferable and codified knowledge.

A second example of tacit knowledge refers to the management of firms. Should firm A take over firm B or leave things as they are? To take a decision involves processing an enormous amount of information and attempting to analyse a multitude of relationships between ill-defined variables. Guesstimates and hunches about future developments are crucial to the outcome. Evaluating the human resources in another firm is a complex social act. In this case, there is no simple arithmetic (depending on future developments, 1+1 may add up to –2, +2 or even +10).[3] It is obvious that the competence needed here is not easily transferred through formal education or information systems. It should also be observed that the decision is unique rather than one in a series of similarly structured problems. Attempts to design formal decision models to cope with this kind of problem will not be successful; the requisite knowledge remains tacit and local. Of course, it is possible to learn the skills of artisans and business leaders, but this learning will typically take place in an apprenticeship-type relationship in which the apprentice or the young business administrator learns by operating in close co-operation with more experienced colleagues.

In short, tacitness has its roots in complexity and in variations in quality. It prevails in situations where it is necessary to use several senses simultaneously, where skilful physical behaviour is involved and where understanding social relationships is crucial. The more rapid and the more radical the process of change, the less meaningful it will be to try to codify knowledge. In a steady state (a circular flow in Schumpeterian terms), a gradual movement from tacit towards non-tacit knowledge might take place.

The impact of information technology

There is a strong bias in Western civilisation in favour of explicit and well-structured knowledge as well as efforts to automate human skills. One early example is the effort to transfer the knowledge of skilled workers into machinery which is connected with Taylorism. Present efforts to develop general business information systems and expert systems go in the same direction. So far, however, automating human skills has proved economically successful only for relatively simple repetitive tasks in a reasonably stable environment (Hatchuel and Weil, 1995). Highly automated process industries may be very cost-efficient, but when the products lose their competitiveness owing to the appearance of more attractive substitutes, they leave behind "rust-belt" problems which may be difficult to solve.

How do recent developments in information technology (IT) affect the different aspects of knowledge? It is claimed that increased use of information technology enhances both incentives and possibilities for codifying knowledge (David and Foray, 1995). While this is certainly part of what is happening, it would seem that the connection between the IT revolution and the role of tacit knowledge in the learning economy is more complicated.

While some skills will take a codified form, demand for complementary tacit knowledge will grow. The very growth in the amount of information available to economic agents increases the demand for skill in selecting and using information intelligently. For this reason, experience-based learning may become more rather than less important. The major impact of the IT revolution on the learning process may be, however, that it speeds up change in the economy. The codification, standardisation and normalisation of certain parts of the knowledge stock increases the rate at which some stages in the innovation process progress, and the diffusion of this kind of knowledge may also accelerate. In order to see why skills and skill formation will remain a core element of economic performance, it is necessary to look at the relationship between learning and change.[4]

Learning and change

Learning and change are closely related and the causality works both ways. On the one hand, learning is an important and necessary input in the innovation process. On the other, change imposes learning on all the agents it affects. In this context, it should be noted that a significant and growing proportion of the labour force is designated to promote change, while change is imposed from above on the rest.

In a market economy, there is a strong incentive to create and exploit novelty. Producing the same thing in the same way is not very rewarding, at least not in the long run. Finding new and more efficient production methods and introducing new and more attractive products in the market are necessary for survival in most competitive markets. In terms of production and interaction with users, learning is fundamental to success in process and product innovation (Lundvall, 1985). Learning involves finding and defining the problems to be solved as well as forming the know-how to help agents find how to solve problems. The ability to learn from experience and to use experience from earlier instances of problem solving is also important.

Learning augments competence and gives people and organisations a basis for introducing innovations. It is equally true, however, that the process of change triggered by innovating actors imposes further change on other agents. When a competitor introduces a more efficient process or a more attractive product, the pressure to change – to adapt or to innovate – intensifies. Consumers, when confronted with new products, have to change their behaviour. And change involves learning. In this sense learning and change are two sides of a self-reinforcing process.

Are learning and change accelerating?

A basic assumption in the learning economy perspective is that the rates of change and of learning have accelerated since the 1980s. There is little doubt that this has been the case over a longer time span: change has accelerated enormously since the beginning of the industrial revolution. But what about the short term? It is not easy to find reliable and valid indicators. The number of scientific articles is growing exponentially, but this may have more to do with the institutional context than with an increase in the rate of learning. Patent statistics and other indicators of technical progress may also suggest acceleration or deceleration, but, again, the institutional setting may be more important than the actual rate of learning in explaining such patterns. The economy's rate of growth is actually slower than in the 1950s and 1960s, and indicators of structural change (changes in the sectoral composition of production and employment) do not give a clear indication. While changes in the structure of employment seem to have slowed in the 1980s, a slight acceleration in the rate of structural change seems to have occurred when sectors are measured in terms of output (OECD, 1994 and 1995).

Given the difficulty of obtaining reliable and valid data, some anecdotal evidence may be useful. In 1993, the theme of the annual conference of European R&D managers (EIRMA) was "Accelerating Innovation". Among the experts present, there was little doubt that there had been an acceleration since the 1980s, at least in some crucial respects. The key to success in innovation is timing, that is, moving as rapidly as possible from the original idea to the introduction of the novelty in the market. The discussion at the conference centred around different methods of doing so. When the activities of strategic agents of change accelerate, other agents in the economy must learn more rapidly.[5]

Another tendency, involving a broader set of actors than R&D-intensive firms, is the movement towards flexible specialisation, where producers increasingly compete by responding rapidly to volatile markets. This has been recognised as a strong trend by academic scholars and consulting firms, and many firms have drastically changed their organisation in order to be able to meet this challenge.

A third phenomenon has to do with the introduction of more intense competition in sectors where firms have lived a more protected life. Competition may come from the entry of firms from a different sector (banking, real estate, insurance, etc.), from opening national markets to imports or from deregulation and privatisation of activities. In all these cases, the rate of change will accelerate more rapidly than in sectors (such as textiles, clothing and household appliances) where firms already accustomed to competition feel the effects of globalisation. The rate of learning will accelerate and stimulate the introduction of new management concepts as well as new forms of organisation.

Empirical data from a major survey of 2 000 Danish firms confirm the basic assumption of intensified competition and accelerating change (Gjerding, 1996; Lund and Gjerding, 1996). A large majority of the firms note that they have experienced more intense competition in the 1990s. Those that point to a dramatic increase in the intensity of competition, in particular, introduce new forms of organisation that are functionally more flexible and increase the qualifications and learning abilities demanded of their labour force. These and other patterns emerging from the survey show a process in which increased competitive pressures result in transformation and selection. Organisations are transformed so that their capacity to cope with and impose change increases. The most change-oriented people are chosen. This is an important mechanism which reinforces the characteristics of the learning economy.

There are thus several indications of more rapid change and learning. The widespread introduction of information and communications technologies (ICT) reinforces this tendency by shortening distance in terms of time and space. As already noted, they also make it easier to codify certain aspects of the knowledge creation process. The use of the Internet for innovation illustrates in extreme form these aspects of the learning economy (Fransman, 1997).

Carter (1994 and 1996) has recently introduced a similar perspective on economic change with an emphasis on "the costs of change". These are resources which are directly committed to initiate, realise and adapt to change. The empirical analysis only covers manufacturing; it demonstrates a strong correlation between the proportion of non-production workers and the rate of change in a sector. Sectors with a high proportion of non-production workers grow more rapidly, their rate of productivity grows more rapidly, and they include the most science-based activities. Carter argues that most of the non-production workers are engaged either in promoting or adapting to change. R&D personnel are the most visible of such workers, but the category also includes many other professions. Why should there be such a large staff of engineers, accountants, sales personnel and managers if there is no or very little change?[6]

Networked knowledge

In his address to the annual conference of the American Economics Association some years ago, Arrow criticised methodological individualism and pointed out that the traditional dichotomy between public and private knowledge is becoming less and less relevant (Arrow, 1994). Hybrid forms of knowledge, neither completely private nor completely public, have become increasingly important. More and more strategic know-how and competence are developed interactively and shared within subgroups and networks. Access to and membership in such subgroups is far from free. This change in the character of knowledge may be regarded as the other side of more generally recognised organisational developments in which the dichotomy between market and hierarchy is challenged by hybrid forms known as industrial networks (Freeman, 1991).

The same may be said for the dichotomy between codified and tacit knowledge. The increasing emergence of knowledge-based networks of firms, research groups and experts may be regarded as an expression of the growing importance of knowledge that is codified in local rather than in universal codes. The growing complexity of the knowledge base and the more rapid rate of change make it attractive to establish long-term selective and durable relationships for the production and distribution of knowledge. The skills necessary to understand and use these codes will often be developed only by those allowed to join the network and take part in a process of interactive learning. Dosi (1996) gives an interesting illustration (the latest Fermat theorem) of the exclusive character of certain types of codified knowledge.

Perhaps one of the most fundamental characteristics of the present phase of the learning economy is the formation of knowledge-based networks, some of which are local, some of which cross national boundaries. The access to such networks may be crucial for the success of firms as well as research teams. The growing importance of the information infrastructures implies that the question of inclusion or exclusion becomes increasingly important. The network form of organisation is flexible but does not necessarily support social cohesion at national level. A more feudal type of society can be envisaged which could run the risk of "intellectual tribalism" (Lundvall, 1995), whereby networks increasingly develop their own internal codes of conduct which are not applied to non-participants.

Why the learning economy is a mixed economy

It has been generally recognised that it is difficult to integrate online information with other assets in neo-classical economic analysis and that the production and distribution of information is characterised by market failure. When the perspective is widened to encompass tacit knowledge and the process of learning new skills, these problems become dramatic.

Learning in general, and especially the process of learning know-how and tacit knowledge in interaction with other people, is strongly affected by trust. Trust is a complex concept, but is has to do with reliability, honesty, predictability and a sense of duty to others. Basically, it is a question of not exploiting unforeseen events to one's sole advantage. There will be more or less trust, and it may extend more or less widely. The learning economy needs a great deal of trust, but trust cannot survive in a pure market context, as Kenneth Arrow (1971) has pointed out: "Trust cannot be bought: and if it could be bought it would have no value whatsoever."

The fundamental role of trust raises questions about another standard assumption of neo-classical theory. It is assumed that, in the economic sphere, it is reasonable to approximate human behaviour to so-called economic man who calculates the outcomes of all alternatives in order to select the one which is best for him. Williamson (1975) brings this perspective to its logical conclusion by assuming that economic man will be characterised by opportunistic behaviour and will act with guile. Instrumental and strategic rationality is assumed to be the norm and the ideal of human behaviour, at least in the economic sphere.

To test this assumption, one may consider what would happen in situations of interactive learning where masters, apprentices, university colleagues and co-operating R&D departments were guided exclusively by such behavioural rules. Organisations, research teams and laboratories where people have a genuine interest in understanding new phenomena, mastering new techniques and sharing knowledge with apprentices and colleagues would be much more successful than one where individual utility is the single goal.

Honesty and trust, embodied in people and in social relationships, may be replaced by formal and informal institutions that keep opportunistic behaviour within reasonable limits or reduce its negative impact. The legal system, the internal proceedings of professional societies and reputation may all help. As these may be costly to establish and reproduce, societies where norms of honesty and mutual responsibility are generally accepted may be better off than those requiring policing. In the learning economy, the importance of this ethical dimension increases enormously. The worst situation is one in which institutions that replace it can not be trusted; the current situation in Russia may be seen as an example.

The learning society has forces which counter the crudest aspects of an individualist, egotistical society, but it also struggles with tendencies towards private gain and tribalism. The increasing autonomy and globalisation of the financial sector and the profits to be reaped from speculation help undermine the learning economy. The greatest threat, however, may come from within the learning economy itself and its inherent trend toward social polarisation.[7]

Uneven distribution of the costs and benefits of change

The most immediate consumer benefits of intensified competition and accelerated change and learning are growing productivity, lower prices and a higher level of consumption. Also, members of innovative and flexible organisations may earn a premium or at least avoid bankruptcy. In newly industrialised areas, there may be quite dramatic increases in per capita consumption, especially in the well-educated segments of the labour force.

Data seem to indicate that, on balance, benefits and costs have become less evenly distributed during the last decade, at least within the OECD area. Profit shares have grown at the cost of wage shares throughout the OECD area since the mid-1970s, while earning differentials between skilled and unskilled workers have widened in English-speaking countries; differences in employment opportunities for more or less skilled labour categories have increased in those countries, as well as in other European countries

(OECD, 1995, pp. 22-23). Differences in income between rich and poor European regions remained substantial throughout the 1980s (Fagerberg *et al.*, 1997).

In the learning economy, there is a contradiction between the exclusion of a growing proportion of the labour force (on whom the costs of change are concentrated) and the growing need for broad participation. It is not clear that a learning economy can prosper in a climate of extreme social polarisation. Social polarisation will directly increase so-called bottleneck problems in the labour market and indirectly it will create a social climate in which the social and ethical basis of interactive learning is weakened. This is why it is increasingly necessary to combine the "old new deal" with a "new new deal". The implications for the development of the knowledge base of the health and the education systems are important (see below).

Two different modes of knowledge creation

A new perspective on the Japanese model

There have been many attempts to explain Japan's extremely successful catching-up and rapid growth in other parts of Asia. Today, this success is being reassessed, and the question of how the United States has revitalised its knowledge-based industries is being raised. Two different models of knowledge creation may help to explain these developments and illustrate the potential usefulness of analysing differences in modes of knowledge creation with an emphasis on the distinction between tacit and codified knowledge. An interpretation of two sources (Nonaka and Takeuchi, 1995; Eliasson, 1996) are used as a basis for this heuristic exercise.

According to Nonaka and Takeuchi, Western civilisation has a strong normative bias in favour of explicit and well-structured knowledge, as reflected in the priority given to formal natural science as an ideal for all other sciences. Engineering disciplines and especially those with a weak science base have much lower status. In practical life, efforts are constantly made to structure and formalise or even automate tacit knowledge. One example is the Taylorist effort to transfer the knowledge of skilled workers to machinery. Present efforts to develop general business information systems and expert systems go in the same direction.

Eliasson shows that automation in the form of generic business information systems has proved again and again to be impractical. An enormous number of articles have been written on the fully automated factory while the real counterpart has been neglected. The same is true of the exaggerated prospects for office automation. In practical terms, this has been costly for many firms. Those that have overemphasised use of business information systems in their decision-making processes have proved to be the least successful (IBM illustrates this point).

Both these sources refer to the desire to automate human skills and to the fact that this desire cannot be realised in a world undergoing rapid change. Nonaka and Takeuchi see the source of this desire in the western (Cartesian and dualistic) philosophical tradition. They oppose this to the theory and practice of Japanese firms whose roots are in a cultural tradition where the separation of mind and body is an alien concept.

Nonaka and Takeuchi show how Japanese firms organise product innovation in ways that explicitly take into account the important role of tacit knowledge. Japanese managers do not give detailed instructions indicating the direction of the work of their innovative teams. Instead, they promote the search for innovative solutions through vague metaphors and analogies based on intuition which leave ample room for creativity and the formation of new intermediate concepts. An intermediate layer of the project team make these concepts interact with the tacit knowledge of skilled workers and engineers. They formulate somewhat more concrete notions and the new product is gradually conceptualised.

Throughout the process, face-to-face interaction and hands-on experimenting is given high priority. Information technology gives participants easy access to information banks to support knowledge creation, but it is always combined with, not a substitute for, human interaction.

It is argued that the organisational model best suited to creating new knowledge is one in which a regular divisional structure is overlaid with *ad hoc* horizontal teams whose role is to create new products and new knowledge. Team members should be removed from their regular function and division.[8]

An alternative model: the experimentally organised economy

Eliasson's major theme is the importance of tacit competence and the limited usefulness of universal information business systems. His analysis covers a broader set of topics relating to firm management than Nonaka and Takeuchi's. It covers, for instance, the need for financial information systems that support efficiency in the short term as well as incentives to create new knowledge and to innovate.

At some points, Eliasson's analysis makes organisational recommendations very similar to those proposed by Nonaka and Takeuchi, such as the idea that horizontal teams that cross the divisional borders are necessary to provoke change. In terms of information technology, it also emphasises facilitating communication rather than on replacing human skills. In important respects, however, the experimentally organised economy is very different and sometimes even apparently the polar opposite of the Japanese system.[9] Eliasson's experimental economy has the following characteristics:

– First, in product markets, low entry barriers and fierce competition create the best environment for promoting experiments and getting rid of inefficient, non-innovative firms. Little is said about long-term inter-firm co-operation.

– Second, in the analysis of the labour market, the top management selects competent teams and designs material incentives to stimulate the firm's top teams. If anything, it is assumed that differences between the earnings of the most competent workers and the others are too small. The idea that, under certain circumstances, social cohesion could promote learning and innovation is not considered.

– Third, the financial market's most important function is to intervene and enforce a removal of incompetent or conservative top management. The US type of capital market, with take-over threats, junk bond markets and venture capital, is presented as ideal. Little is said about the problem of short-termism in Anglo-Saxon financial markets.

– Fourth, governments should not intervene in the market mechanism because they are incompetent to recognise and correct their own mistakes, whereas this is a key competence of successful firms. There is no reference to cases where active governments have stimulated economic development, for instance by indicating broad trajectories for industrial development.

One element that distinguishes the two models is that Eliasson's has a more hierarchical understanding of competence. Operators at the bottom have a very limited role to play in learning and job creation. This may be explained by an almost exclusive focus on tacit knowledge as "business decision competence" and the corresponding neglect of tacit knowledge connected sometimes to direct physical human action. Eliasson does not explicitly refer to the separation of mind and body, which Nonaka and Takeuchi see as a major element of the Western model. Perhaps it is not unfair to say that Eliasson's criticism of neo-classical rationalism remains rooted in the Cartesian tradition.

Two development models: Western and Eastern

These two models help to construct two different models of economic development, both based on the idea of "a learning economy". The Western and Eastern models do not actually exist but the first is closer to American economic organisation, while the second is closer to Japan's. Behind the systemic national differences generally recognised in comparative studies of US and Japanese firm and inter-firm organisation and institutional structure, there are differences in views of knowledge creation and especially of the relative importance of tacit knowledge.[10]

In the Western model, the firm's organisation presents a clear hierarchy in which the main responsibility for promoting innovation is at the top. This responsibility is performed by hiring, firing and promoting competent people and by designing incentive systems. Monetary incentives predominate and differences in competencies are reflected in inequalities in earnings. Specialised expertise is the most crucial element of problem solving. In the Eastern model, instead, medium-level team leaders are at the core of the innovation process. Top management directs innovation by throwing out metaphors and analogies. They establish framework conditions that promote face-to-face interaction and hands-on experimenting in order to mobilise and develop tacit knowledge at all levels of the firm. Monetary incentives are secondary and income differences are suppressed. Job circulation is stimulated in order to avoid narrow specialisation.

Regarding inter-firms relationships, the Western model makes competition dominant. Industrial markets as well as markets for consumption goods are characterised by arm's length and anonymous relationships between sellers and buyers. Markets serve as a medium for information exchange when tacitness of knowledge blocks organisational learning. By contrast, in the Eastern model, markets are characterised by long-term relationships between sellers and buyers who transmit qualitative as well as quantitative information (Sako, 1992). Direct interaction with customers is crucial when creating new products.[11] Creation of trust and communication channels is crucial to developing and introducing successful new products.

These differences are also reflected in the broader institutional structure in terms of labour markets, financial markets, knowledge infrastructure and regimes of governance in national innovation systems (Lundvall, 1992; Nelson, 1993). Long-term relationships, in-house labour flexibility and in-house knowledge creation dominate in the Eastern model, while short-termism, numerical flexibility and extended division of labour in knowledge production characterise the Western model.

Efficiency of the two models of knowledge creation in the learning economy

Until recently, there was a general tendency to regard the Japanese system as superior for transforming innovation into international competitiveness and economic growth. New products were developed more quickly that in the United States and the product was brought into production more efficiently (Dertoutzos *et al.*, 1989; Freeman, 1987).

Recently, as the Japanese economy has slowed while the US economy flourishes, this view has been challenged. It may be – a topic to be explored – that the rate of change is now such that long-term, stable relationships become sources of rigidity rather than flexibility (Dore, 1986). US firms have been freer to combine and recombine in new networks as knowledge requirements have changed. Their links with Asian partners in international production networks may also have helped them to find a better mix by integrating elements of the Eastern model (Ernst, 1997).

A shift in which one model moves from superiority to its opposite is not new in the history of economic development. The United Kingdom and the United States have gone through such experiences. In order to know whether the shift is permanent, it is extremely important to learn if the present characteristics of the learning economy are here to stay or if we are in a transition period and a slowing of the rate of change will follow. Most of the major factors at work – globalisation, deregulation, codification of elements of the innovation process – seem to reinforce the acceleration, but history also tells us that no trends go on forever.

The aim of this stylised account of Western and Eastern systems of knowledge creation is to inspire an analysis of knowledge creation in health and education that takes into account:

– The systemic nature of knowledge creation.

– National differences in modes of knowledge creation.

– Differences in how tacit knowledge enter the process of knowledge creation.

A new setting for knowledge production

The learning economy, like any other society, has internal contradictions, some of which should receive special attention when considering the role of knowledge creation in the education and health systems. This section therefore looks first at the importance of the social and ethical dimensions of the learning economy. Second, it is argued that the role of tacit and codified knowledge in learning may be a key to rethinking the health and education systems.

In terms of the social dimension, selection mechanisms in the labour market change when accelerated change results in more demanding requirements in terms of workers' learning ability. This is reflected in increased polarisation of job opportunities and income. When a growing proportion of the labour force cannot earn a decent income by ordinary honest work, the learning economy is undermined and a "new new deal" is needed. In the "old new deal", social policy, income transfer policy and environmental policy had a repair function which defined losers *ex post* in the economic race. In the "new new deal" the focus is on reducing the losers' handicap before they enter the race and on supporting them throughout. In both education and health policy, this calls for new priorities, both in general and in terms of the direction of knowledge creation.

In terms of the moral dimension, economic efficiency in the learning economy depends increasingly upon interactive processes of learning; the ability to co-operate and establish mutual trust is fundamental. Without subscribing wholeheartedly to Fukyuama's (1995) somewhat biased interpretation of the concept of social capital, its general intention captures important aspects of the learning economy. The drive for ethical company strategies should also be seen in this light. Education and health are the core of the ethical dynamics of the learning economy. During their education, young people form the ethical standards that will govern their behaviour in civil society and the economy. Health is an area where conflicts between commercial interests, scientific ambition and human values will be dramatic in the near future. Because these conflicts relate to the fundamental issues of life and death, they will tend to spill over to society as a whole.

The comparison of the Japanese and US models of knowledge creation presented above is important for two reasons. First, it shows that knowledge creation typically takes place in a systemic context. Second, it brings out cultural differences related to how tacit knowledge is regarded and treated in learning organisations. Both of these aspects may be important for analysing knowledge creation in health and education.

When considering the design of sub-systems in a specific country, it is important to take the systemic context into account. Different elements (training of experts, governance mode, organisational mode, division of labour between different professions, role of users, criteria of success) will be related. Often they will reflect the characteristics of the national system. Therefore, an attempt to harmonise such subsystems in one dimension while neglecting systemic characteristics may lead to unexpected results.

Both in education and health, understanding the role of tacit knowledge in knowledge creation is fundamental. In education, a more positive assessment of tacit knowledge as a key element in the learning process may be one way to reduce the early polarisation of students in the education system. In general, it might help to produce a more competent workforce. In the health sector, there seems to be a growing tension between a science-based institutionalised activity and one based on "alternative medicine". Giving tacit knowledge a more legitimate position may help to break down mutual prejudice in this field.[12]

Knowledge creation in the health system

This section offers some reflections on the implications of the learning economy for the health sector. Certain issues referred to above will be addressed somewhat more specifically.

Where are the limits of the health system to be set? In the learning economy, it is important to operate with a broad definition and to give serious attention to the interface with the whole socio-economic system. Recently, European analysis co-ordinated by scholars from Amsterdam demonstrated that differences in health conditions are more strongly correlated with the social situation in Denmark than in countries as Portugal and Greece (The Danish Journal : *Information*, 8 April 1998). The data indicate a fundamental weakness with the "old new deal". There is a more stringent selection mechanism in the Danish high-income labour markets and a more marked psychological effect on the quality of life of those who are excluded. There is also weak development of the prophylactic aspects of a health system that is unable to affect the detrimental life styles of socially excluded citizens. The health sector's knowledge base may give too much attention to fancy scientific discoveries and new methods of treating exotic diseases. More mundane activities such as systematic attempts to train people to stay healthy may be neglected. Especially in a period characterised by social exclusion, it is important to develop the part of the knowledge base that concerns prophylactic and social medicine.

This has, of course, to do with the organisation, incentive system and governance of the health system. Knowledge production is torn between academic career incentives, direct profit incentives and social needs. The high risks involved and the need to ensure a minimum of security for patients also play an important role in the organisation of the health system. Media interest in (both positive and negative) sensational stories about medical treatment further complicates the picture and leaves a good deal of leeway for playing complex games in competing for research funding. Even rather simple changes in organisation may result in dramatic improvements in performance (Andreasen *et al.*, 1995). This implies that organisational and socio-economic research efforts should receive more attention when considering the health system's strategic knowledge base.

Certain recent developments tend to increase ethical tensions and dilemmas in medicine. To the old problem of designating priorities between activities in areas where life and death are at stake, new moral dilemmas have been added. Organ transplants, new ways to overcome fertility problems, genetic manipulation and other new techniques and insights increase the ethical difficulties involved in decision making. New genetic breakthroughs that make it possible to foresee more precisely an individual's risk of getting specific diseases contribute to the problem: should doctors operate on high-risk breast cancer patients before there is a clear diagnosis of a tumour? The point here is that the ethical dimension is becoming so important that it must be regarded as a core element of medicine's knowledge base. It must become an integral part of training programmes and play a key role in institutional design, including the code of conduct in research.

In general, the learning economy gives high priority to rapid results that can be exploited commercially. This also affects the health sector in different ways. Pharmaceutical companies and other major private interests exercise a strong pull on the direction of knowledge creation in the health sector which will not always coincide with a response to social needs. The tension between the socially and ethically acceptable and market pull is growing in many areas, and effective mechanisms that allow key actors to stick to fundamental ethical principles are important. To leave the problem to be solved by the scientific community may be to overload it in terms of the responsibility it can efficiently manage. Inculcating ethical principles in profit-oriented organisations is difficult but probably part of the solution.

Another part has to do with broadening the public debate on health priority issues and give this a central place in democratic political debates. The complexity and fundamental character of the issues involved are such that developments in the health sector may increase the tensions in a polarising learning economy. An open and democratic debate with wide participation and a creation of user organisations that balance the impact of market forces and academic career incentives is called for. This requires a stronger focus on the sociological and organisational elements of the knowledge base.

Knowledge creation in the education system

The education system obviously has a key role to play in the learning economy. At the same time, it should be realised that formal education is only one, but an important, aspect of the learning economy. Learning as part of everyday economic activity has become much more important. Economic success reflects the capability of regions and organisations to mobilise many different institutions (firm organisation, networking, knowledge infrastructure organisations, incentive systems, etc.) in support of learning. This points to a need to operate with a broad definition of education and especially to the importance of the interface between the educational and the broad socio-economic system. The interaction between everyday learning and formal education is a key to resolving some of the most fundamental contradictions in the learning economy.

Competence building can be the outcome of formal training in specific institutions (schools and universities), of learning by doing in ordinary work situations and of a combination of the two. Rethinking the relationships between the two spheres of competence building is necessary to take on the challenge of accelerating learning and compensating weak learners. What will matter in the future is the capacity to learn, and the distribution of this capacity will determine the economic fate of individuals, regions and organisations. This observation has far-reaching implications for the education and training system and for what will matter most in its knowledge base. New pedagogical methods and new insights in social psychology need to be linked to insights about socio-economic developments and organisation theory to confront these issues.

The ethical dimension will become increasingly important in the learning economy. To foster empathy and willingness to care about the interests of others, especially of those who become "losers", is a major function of the school and training system. In the private sector, it will prove difficult to build learning organisations without practising fairness and honesty in the organisation and in its dealings with external partners. For the school system, it is not a question of preaching the importance of being good to other people but rather a question of creating incentive systems and practices that support such values. This calls for a broad definition of the knowledge base so that it includes the formation of internalised codes of conduct.

Much training in formal institutions gives (too) strong emphasis to codified knowledge and to know-what and know-why. A great challenge to pedagogical research is to analyse the degree to which training can exploit more efficiently the spiral of tacit-codified-tacit knowledge. Problem-oriented and practice-related methods that focus on creating know-how may reduce the gap between formal training and what goes on in the regular labour market. Group work and practice in communicating what has been learnt to others are methods that can strengthen competence in "know who" knowledge.

One of the most fundamental characteristics of the learning economy is the high rate of change in the market sector. Education and training systems will always tend to lag behind the most dynamic parts of the private sector with respect to the skills and competencies they can inculcate. In the learning economy, the gap tends to widen as the rate of change accelerates. One way to narrow the gap is to strengthen the practice-oriented elements in the formal education and training system and of course to develop new forms of co-operation between knowledge institutions and the business sector.

Conclusion

This paper argues that knowledge creation increasingly takes place as a process of interactive learning inside organisations and in networks of organisations and that this is what is at the core of modern economic dynamics.

It is the acceleration of this process that is reflected in the social polarisation of labour markets, the most important negative side of the learning economy. Because it risks undermining social cohesion, any strategy aimed at supporting the learning economy must include a "new new deal" in which special attention is given to strengthening the learning capacity of weak learners. This is important, since the learning economy needs to have a reasonably firm ethical base to function well. It is not possible to create "intellectual capital" efficiently without having "social capital" as a major input.

In western culture there is a bias in favour of codified knowledge and too little attention has been given to the role of tacit knowledge in learning processes. By reducing this bias, problems in the learning economy may be resolved.

The health and education systems play key roles in the development of the learning economy. The design of the institutional framework for knowledge creation in these systems may have a major effect on the socio-economic dynamics of the learning economy. There is a need to promote knowledge creation and learning at the interface between these systems and the rest of society. Further acceleration of knowledge creation along the specialised trajectories already established may heighten the internal contradictions in the learning economy.

NOTES

1. Arrow (1962) has pointed out that innovation is not an ideal phenomenon for this kind of analysis because its most fundamental characteristic is that it gives rise to something not known in advance and that it is not possible to apply the principle of rational choice if the set of choices is not defined in advance. However, new growth theory, for instance, operates with models that combine ongoing innovation with assumptions of rational choice.
2. The concept of tacit knowledge was originally developed by Polanyi (1958/1978 and 1966).
3. These are typically situations where cultural differences make it difficult to interpret the facts obtained. After negotiations broke down, French managers involved in attempts to merge Renault and Volvo described the difficulties in establishing a clear picture of the internal dynamics of the other firm.
4. It should be emphasised that IT may be regarded from a different perspective when the emphasis is on its potential to reinforce human interaction and interactive learning. Here, the focus is not on its capacity to replace tacit knowledge but rather on how it can support and mobilise tacit knowledge. E-mail systems connecting agents who share common local codes and frameworks of understanding can have this effect. Broad access to data and information among employees can further the development of common perspectives and objectives. One interesting issue is whether the new virtual reality and multimedia technologies can replace direct human interaction when it comes to transferring elements of tacit knowledge.
5. In his introductory remarks, the president of EIRMA, Dr. E. Spitz, stated, "In a time of intensive global competition, speeding up the innovation process is one of the most important ingredients which enable the company to bring to the market the right product for right price at the right time (...). We know that it is not only the R&D process which is important. We have to put emphasis on the integration of technology in the complete business environment – production, marketing, regulations and many other activities essential to commercial success. These are the areas where the innovation process is being retarded. This subject is a very deep-seated one which sometimes leads to important, fundamental rethinking and radical redesign of the whole business process. In this respect, especially during the difficult period in which we live today, where pressure is much higher, our organisations may in fact, need to be changed" (EIRMA, 1993, p. 7).
6. A recent development, sometimes referred to as outsourcing, may be interpreted as an externalisation of some of these costs of change. A series of studies starting with Antonelli (1997) has shown how, across industries, there is a strong correlation between the rate of productivity growth and growth in the use of knowledge-intensive services.
7. Fukuyama (1995) focuses on trust as "social capital" and argues that it tends to be eroded, at least in the United States. To a European, the analysis may appear somewhat biased by the definition of what is at the core or social capital, but the basic intuition of the importance of social relationships for economic efficiency are to the point.
8. The model is more complex than these remarks indicate. For instance, it assumes that the process is a spiral movement from tacit to explicit knowledge, then back to tacit knowledge. The conversion of one to the other plays a crucial role in the theory. This is a point worth critical attention. In some of Nonaka and Takeuchi's examples, it is not clear whether interaction between different forms of knowledge or conversion of one to the other is illustrated.
9. The only explicit important reference to the Japanese model appears to be that to the Aoki juxtaposition of the A model and the J model of work organisation; Eliasson emphasises that the J model hampers innovation (1996, pp. 109-110).
10. Lam (1998) presents a fascinating story of the kind of problems that arise when the two cultures collide when they attempt to collaborate in knowledge creation.
11. Nissan's development of its Primera model for the European market is an interesting illustration of how Japanese firms try to absorb local tacit knowledge from potential overseas markets in Europe (Nonaka and Takeuchi, 1995, pp. 200 et *passim*).
12. Activities of an international organisation such as the OECD may sometimes reinforce some of the problems. "Benchmarking" is much easier in areas dominated by formal training and codified knowledge. It may be tempting for Member countries to aim at approaching a fictive best practice (or to converge towards an OECD average) for isolated variables rather than take into account systemic features of the domestic sub-system.

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INDUSTRIAL POLICY, COMPETENCE BLOCS AND THE ROLE OF SCIENCE IN ECONOMIC DEVELOPMENT: AN INSTITUTIONAL THEORY OF INDUSTRIAL POLICY

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Introduction

This paper makes use of the concept of "competence bloc" to examine the role of science and of policy makers in the spontaneous or designed creation of innovative industrial districts, notably around university campuses (science parks). Science parks on university campuses, industrial parks and technological incubators are all artificial policy devices designed to be part of national industrial policy programmes. Most are located around a university with the express purpose of making it easier for firms to draw on the research generated there. Silicon Valley, the best-known spontaneously created competence bloc, would not have come about were it not for the presence of certain institutional circumstances.

The competence bloc, however, does not automatically imply dynamic economic growth. It defines the requisite actors for an innovative process but cannot, alone, set that process in motion. It also requires the incentives and competitive push of the *experimentally organised economy* (Eliasson, 1987*a*; 1991) and a link between the outcomes of experimental innovative search and the economy. The experimentally organised economy is characterised by: *i*) lack of transparency from any position in the bloc or investment opportunity set; *ii*) bounded rationality; and *iii*) tacit knowledge. Therefore, entrepreneurial mistakes are a normal feature of the dynamic economy and a standard cost of economic development (Eliasson, 1991; 1992). Innovative entry and forced competitive exit are essential to economic growth.

Advanced firms often unintentionally diffuse research results through other industries and therefore function as technical universities (Eliasson, 1995; 1997*c*). To ignore this private externality is to misunderstand the nature of technical change. Efficient policy will also facilitate the diffusion of such privately generated spillovers to other industries. This requires institutions that make it possible for the spillover-generating firms to charge for the positive externalities they create.

These externalities often take the form of people with knowledge who move between jobs. Hence, functioning labour markets are necessary to the functioning of the competence bloc and the efficient commercialisation of research carried out there. In addition, much creation of new industry based on innovation occurs when entrepreneurs in university labs or advanced firms leave to establish their own business. However, it is important to be able to use new knowledge in an industrial context. Technical knowledge must be integrated with economic considerations, mostly by selecting those technological solutions that meet profitability criteria. The necessary receiver competence (Eliasson, 1986; 1990*a*) is rarely acquired in a university environment.

To understand new industry formation and economic growth, it is therefore necessary to specify all the competencies needed to build an industry from certain scientific knowledge and ensure that they are available. When they are, the conditions for the knowledge-based information economy have been met (Eliasson, 1987*b*; 1990*b*).

Finally, since the goal of a science park is to promote economic growth, attention must be given to the knowledge capital associated with economic growth, which is much more than the knowledge created in and around universities and science parks.

The following sections present, first, the relevant theory, including the notions of spillovers, competence bloc and the experimentally organised economy. Second, the creation and diffusion of industrial knowledge are described, with academia placed in the broader context of scientific, engineering and industrial knowledge creation. Third, the science park is introduced in the context of a competence bloc, and the policy problem is defined. Finally, some cases are examined and conclusions are drawn.

Spillovers, competence blocs and economic selection

It has long been thought (*e.g.* Nelson, 1986; Jaffe, 1989) that scientific principles, elaborated in universities and engineering schools, contribute to industrial progress as they are converted into engineering applications. Some suggest, however, that scientists and university engineers do little more than encode the principles of existing applications (innovations). Others argue, in fact, that a university environment is not creative enought to support truly innovative discovery. Hence, new business ideas should be sought in experimental environments, where actors have to be innovative to survive. As new empirical studies tend to support this view, an important part of this analysis will be to give science and the university a documented role in industrial development.

From technology to industrial spillovers

A quick glance at the realities of new industry formation (Eliasson, 1995; 1996*b*; 1997*b*; 1997*c*) reveals that spillovers are industrial rather than technological. To reach the stage of successful industrial application, a new technology is filtered through a competitive market process which involves complex competencies. It should be noted that the studies reporting strong and significant technological spillovers are based on instances where such competitive screening has taken place. They do not support the idea that expanding resources to science and new technology development will automatically enhance industrial competitiveness and technological development. Rather, attending to the process of economic filtering may be the most efficient way to put industrial life into dormant innovations in academia or business. This is a matter of institutional policy.

The competence bloc

The competence bloc is the configuration of actors that initiates and stimulates the growth of an industry. They are: competent and active customers, innovators who integrate technologies in new ways, entrepreneurs who identify profitable innovations, competent venture capitalists who recognise and finance entrepreneurs, secondary markets which facilitate ownership change, and industrialists who take successful innovations to industrial scale production (Eliasson and Eliasson, 1996). A competence bloc is defined in terms of end results, a bundle of functionally related products in the market, not in terms of technologies or physical inputs,[1] and its dominant function is selection of winning technical and economic solutions. This selection involves joint minimisation of two errors: allowing losers to survive too long and rejecting winners. Under such circumstances the competence bloc will develop faster than the sum of outputs of its constituent actors.

A minimal critical mass and variety is needed before a competence bloc becomes self-propelling. The policy problem is whether policy catalysts can initiate a competence bloc and/or induce it to reach critical mass faster as well as whether such catalysts can be found in the science community.

The innovative nature of the output selected and produced within the competence bloc is limited by the competence of the customers. Competent customers are always present in innovative and advanced industries. The innovator integrates different (new and old) technologies in an innovative way. The entrepreneur searches actively for and identifies commercially viable innovations and prepares them for market entry.[2] The entrepreneur needs financing from understanding and competent venture capitalists who provide risk (equity) financing at reasonable rates. Reasonable rates require a venture capitalist able to understand the business proposed; such venture capitalists are extremely rare when the innovation is outside the technology range of traditional industry (Eliasson, 1997*e*). The venture capitalist in turn may want to exit his investment at a good return, so that a functioning secondary (initial public offering – IPO) market is necessary. Finally, industrial competence is needed to move the invention to industrial-scale production and distribution. This entire chain of competent actors is necessary to create a viable new industry, and the industrial knowledge of the actors at each step is part of the competence specification. Together, they create the potential for increasing returns to innovative and entrepreneurial activity that characterises the experimentally organised economy (Eliasson, 1991). All actors in the competence bloc must be involved, and there must be a well-structured property rights system (Eliasson, 1998) which minimises the risk of predatory imitation (patents, copyright).

To summarise, the competence of the actors determines the quality of the selection. Incentives are determined within the competence bloc and depend on the presence and competence of all actors. Competition is determined within the competence bloc and depends on the number, variety and character of actors, in short the successful selection of winners.

The question of whether innovations are mainly supply/technology-driven or customer/demand-induced has long been debated. Ultimately, of course, all innovations are customer/market-tested, and technological innovations that lack customer value fail. Customers may induce innovations, and there is presumably then a market. If, instead, innovations arise spontaneously from technical change, they require that the actors in the competence bloc have the necessary incentives and can engage freely in "technological" competition to bring the innovation to the market. The variety and number of actors (due in part to incentives) determine the ability of the system to identify rather than reject winners. A steady flow of winners determines the level of competition that forces incumbents to reorganise or rationalise and inferior firms to exit. The question then is whether a model that integrates these actors is sufficient to explain new industry creation, or if some other externality, call it "culture", is needed.

Experimental organisation and growth via competitive selection

The search for innovations is linked to the notion of a non-linear economy with phases of unpredictable behaviour, the extent of which depends on the organisation of the economy, the variety of its knowledge base, incentives to search and the intensity of competition. The organisation of the competence bloc defines the nature and variety of the knowledge base and the investment opportunity set.

In the vast, non-transparent competence bloc of a successful industry, no actors are safe from devastating competitive entry into their markets. Incumbent firms constantly have to take precautionary action (through reorganisation and rationalisation) in anticipation of unpredictable competitive entry or risk business failure and exit. Therefore, other incumbent actors are forced to become more competitive and force exits. As a result, economic growth in the experimentally organised economy takes place as competitive selection through the four growth mechanisms: innovative entry, reorganisation, rationalisation and forced exit (Eliasson, 1996*a*, p. 45).

Ideally, a theory would be needed that captures the dynamics of reorganising production across the boundaries of existing firms through mergers and acquisitions (M&A). So far, however, no such theory exists. The model of growth through competitive selection or the experimentally organised economy makes it possible to: *i*) identify roles for science and the policy maker in the endogenised growth process; and *ii*) characterise differences in these roles for different industries. What role does each play in the new industries developing through competitive entry such as information technology (IT) or biotechnology, on the one hand, and in the reorganisation of existing mature industries such as advanced engineering, which face intensified competition at their low performance end, on the other?

How are spillovers (competence) diffused?

The diffusion process from sources of spillovers (technical universities and advanced firms) follows four main paths: movement of competent personnel; establishment of new firms by entrepreneurs leaving other firms; learning from and by subcontractors; and learning from technological leaders. The first two paths are the most important. If the labour market does not work well and the conditions for entrepreneurship are not well developed, there is likely to be little formation of radically new industries. Technology diffusion through subcontracting networks and simple imitation belongs more to mature industries with an established and fairly well-known body of knowledge, notably engineering industries. In the aircraft industry, the second and third paths dominate, while in the computer and communication (C&C) industry the first and second are the most important.

For the creation of radically new industry, the competence bloc's entire selection process is needed. Special attention is drawn to the need for a viable, varied and competent venture capital industry, which is missing in many industrial countries, notably in Europe, so that there is little entrepreneurship outside existing industries (Eliasson, 1997*e*). The main competence function of venture capitalists is to identify and understand entrepreneurial winners such that they dare to supply finance at reasonable costs (Eliasson and Eliasson, 1996) Public risk capital, which is influenced by political decisions, tends to be incompetent in this kind of selection process.

In sum, putting dormant technology to work in commercial and industrial applications requires involving the entire selection process of the competence bloc so that channels of diffusion become functional. This, in particular, requires entrepreneurship close to advanced firms and academia and a labour market for competent people. Often supporting policy changes to remove barriers to change (deregulation) are needed.

Knowledge creation and diffusion

The sources of industrial and scientific knowledge are usually not the same. Science does not normally concern itself with the commercial value of its discoveries. It builds knowledge, which sometimes becomes a technology. For innovative technical knowledge to become industrial and commercially viable, the other actors of the competence bloc have to be brought in. The economic filtering of technical innovations, in particular, is critical for the business application and success of scientific knowledge and technology.

The firm as a technical university

Once the presence of technological spillovers from advanced firms is recognised, the latter can be viewed as technical research institutes or universities (Eliasson, 1995; 1996*b*; 1997*c*). The empirical evidence is overwhelming. Almost the entire US IT and communications industry has been founded on spillovers from firms (Eliasson, 1996*a*). To discuss industrial knowledge creation, it has to be understood how successful innovations are filtered through the economic system and surface in the form of new industry creation and how less successful innovations are sorted out and discontinued. This takes place within the competence bloc.

Five different types of production draw more or less directly on scientific knowledge. It is particularly interesting to clarify the differences between industries developing through new entry and exit and industries growing through reorganisation and rationalisation.

First, there is mature production which is potentially in crisis, exemplified by engineering industry, a mature industry with technological roots in the industrial revolution and the industrial backbone of the industrialised world, notably in Europe and Japan.

Second, there is new entry production exemplified by two sectors. One is the C&C industry, a new, well-established, but still rapidly innovating and expanding industry, and a technology which has dramatically reshaped the industrial landscape over the last couple of decades. The second is the the biotechnology and health care industry, in its modern form an industry with great potential and firmly based in science.

Third, there is infrastructure production, again exemplified by two sectors: one, the financial services industry, an old industry which has been completely restructured owing to C&C technology; and second, education and research, an old, academically based industry in need of product innovation and reorganisation.

The engineering industry has been innovating for two centuries. Its knowledge base is dominantly organisational. Its leading firms engage in large-scale production, often in global distribution, and excel in integrating advanced mechanical technology, information and communications technology and new materials, most of which are developed in engineering firms. The engineering industry does not use highly educated workers extensively, except for particular applications such as advanced engineering computation and new materials development.

Advanced engineering product development, manufacturing and distribution embody a dominant organisational technology designed to integrate a number of diverse technologies. This integrated technology, which is developed gradually, is holistic and largely experience-based. While its various component specialities can be taught in classrooms, crucial holistic capacities, such as those embodied in design teams in the aircraft industry, are developed and transferred on the job. Since the aircraft industry already uses the technology of future engineering industry, its engineers are attractive in the labour market (Eliasson, 1995).

The C&C industry increasingly has the same organisational technology as the engineering industry, but it also advances by breakthrough specialist technologies which have revamped the entire industry, as demonstrated by the five generations of computing, the last of which, with the merging of computing and communications, is largely organisational.[3] All of these specialist technologies were developed in industry laboratories[4] and commercialised in new firms. Paradoxically, this industry is based almost entirely on indigenously generated technology (Eliasson, 1994*a*; 1996*d*). It does not make particularly intensive use of highly educated people, but it has been extremely innovative and entrepreneurial.

Biotechnology is firmly based in new scientific discoveries and has obtained new technology directly from academia. Biotechnology in particular makes intensive use of highly educated people (Eliasson, 1994; 1996*d*).

The financial services industry constitutes a fourth production category because it is a pure service industry, because its product technology has been designed in academic settings, because it has been radically restructured through the use of C&C technology, and because its reorganisation is forcing radical change in the global economy. It uses highly educated people fairly intensively.

The education industry, of course, makes the greatest use of highly educated people. While most of it is in public domain and protected from competition, it is a very large industry; in Sweden in 1991, it represented more than 20% of total resources.[5] As it is gradually being opened up through privatisation, not least through more education on the job, it is becoming an increasingly important industry.

The role of academia in science-based industry

While science thrives on specialisation, industry thrives by integrating specialist technologies into technologies with a potential for industrial and commercial application. Also, industry thrives on organisational competence, something that is not particularly characteristic of academia. While the business manager works through other people, academics do not particularly appreciate being managed (Eliasson, 1996*d*). As a consequence, the two environments have very different traditions and attitudes to work.

There are few instances of academically developed technologies that have formed the basis for business. The biotechnology industry is a notable exception, the only genuinely science-based industry based on entrepreneurship around academic laboratories (Eliasson and Eliasson, 1996; 1997). The academic and industry laboratory environments in biotechnology are very similar, and scientists move rather freely between academia and business. It is still unclear whether this "exception", which is rapidly becoming a big industry in the United States, depends on the technology or whether we are witnessing the first stage in the formation of a new industry. While the role of academia in engineering and the C&C industry is to furnish educated graduates, biotechnology is based on entrepreneurship linked to academic discoveries and a political and academic system that supports entrepreneurship. Silicon Valley stands as an example of a competence bloc with all the necessary actors actively contributing to the commercialisation of scientific discoveries.

The standard academic story is that the role of the university in spillovers is the research it produces. This is not true. Academic research rarely reaches industrial laboratories; the main role of academia for industry has been teaching.

The role of science parks in economic growth

New industries like biotechnology which draw directly on academic research will become increasingly important. Industrial laboratories will increasingly recruit academically trained staff with a doctorate and research experience to develop their most advanced technologies, *i.e.* those in which wealthy industrial nations have to excel to remain competitive. This will mean a radical overhaul of existing attitudes, organisation and practices in western universities (Eliasson, 1994; 1996*d*). Many studies, furthermore, have observed a strong skill bias in technological change which will require support of education and possibly academic research (Eliasson, 1987*b*, 1994*b*; Berman *et al.*, 1997).

Science parks

Science parks are fashionable in industrial policy discussions, as a means of creating jobs and, perhaps, exports, and more recently with the express purpose of creating technological spillovers to support long-term economic growth. They are called "industrial parks" or "technological incubators", thereby signifying a more or less "scientific" or "industrial" orientation. However most are predominantly "technical" in orientation, and insofar as industry creation and economic growth are the goal, the prerequisites for success described above are typically missing.

The regional dimension

The literature on science parks focuses on the physical and geographical dimensions, thereby unfortunately ignoring important economic factors. Innovations or new technologies are often assumed to diffuse mechanically along a direct path. The definition of a science park, as formulated by the European Commission's Directorate General XIII, appears to be widely used, not least in Sweden: "A science park is normally a development project involving a site which: is in physical proximity to or has operational links with one or more institutions of higher education or centres of advanced research; is designed to encourage the formation and growth of knowledge-based firms; facilitates, through active intervention, the transfer of technology from the research and academic institutions on site to the firms and organisations based on the park or its surroundings (Sprint Programme DGXIII)." A competence bloc may coincide with a region. This would be the case if Bavaria and Schwaben (Munich and Stuttgart) were only specialised in making luxury cars, but this is not the case. Bavaria also has the German C&C competence bloc, while Silicon Valley has the world's dominant C&C and biotechnology competence blocs. While geographical proximity matters (Mercedes, BMW, Porsche, Audi and Bosch are all within commuting distance), the integration of technology and competence increasingly occurs over large distances via C&C technology, and the more so the closer the activity to standardised industrial-scale production and distribution. Virtual reality is, in fact, rapidly becoming an industrial reality. A geographical or regional definition of a competence bloc or an industrial park shuts out awareness of various important aspects by assumption.

The rationale for a science park is its organisation as a source of spillovers (externalities). Such spillovers may, however, be dormant and need to be activated. Entrepreneurs to put them to industrial use may be lacking. Hence, a science park is best viewed as an "intermediator" between academia and industry with respect to technical or other services produced in academia. It must cover the entire competence bloc to complement the competencies academia lacks. Many of its tasks require business knowledge and experience.

Strategic or spontaneous spillovers

A distinction should be made between deliberate (planned or strategic) and spontaneous spillovers. By definition, a science park embodies a strategy to support the generation of spillovers. It is a currently fashionable policy to commercialise the technology in a stagnant defence industry. However, it is questionable whether strategic spinoffs can be "better" than spontaneous ones. They have often failed dramatically. The issue is whether the best practice is to improve conditions for spontaneous spillovers or to try to select and commercialise particular technologies: "picking winners". On the basis of the arguments advanced here, it is much more efficient policy to ensure that all actors in the competence bloc are present rather than to encourage and/or support particular industries or to attempt to commercialise particular technical innovations.

Spillovers and economic growth

To link academia and the science park to economic growth, it is necessary to recall the four fundamental mechanisms of economic growth: innovative entry, reorganisation, rationalisation and forced exit. The table below identifies the principal role of a science park as an intermediator between academia and technology diffusion mechanisms.

The European Commission's definition of a science park is inappropriate if the purpose of the science park is to function as a catalyst for economic growth. It is too technical and too physically and geographically defined. To be economically meaningful, the science park has to be more broadly defined to include all the actors and institutions of the competence bloc.

Role of universities	Role of science park	Channels of diffusion/Role of government
Supply of educated and talented people		Functioning markets for competence ("labour market")
Supply of research results	Intermediary	Institutions (incentives): patents, imitation
University entrepreneurs (new establishment)		Functioning competence bloc

Case studies

The best way to give credibility to the argument presented above is to support it by case studies. These are taken from the engineering industry, from C&C technology, from biotechnology and from financial services. Two, Kockum's off-shore systems and helium recycling in the United States, have not been reported elsewhere and are described in greater detail.

Mature industry, possibly exiting production

The aircraft and submarine industry

Aircraft and submarines have a very long life,[6] are very complex and are developed and manufactured under very complex circumstances. Today, aeroplanes or submarines cannot be designed, developed and manufactured in a single firm. Production is subcontracted via the market; its organisation is often called integrated production (Eliasson, 1995; 1996*b*). Integrated production requires a holistic approach, and the productivity potential depends largely on choosing the right organisational mix. Since aeroplanes are modernised at least two or three times over their life cycle, a designer who allows for easy repair and modernisation makes the product cost-efficient over its life cycle.

The aircraft and submarine industry, furthermore, are top integrators of advanced forms of three technologies: mechanical technology, electronics and new materials. The organisational and technological integration in the production of large, complex long-lived products stands at the top of the engineering industry technology; it has been developed and implemented in advanced firms, not in academia. The complexity of the integration, furthermore, makes it virtually impossible directly to imitate successful solutions. Both advanced competence *per se* and the relatively satisfactory protection from easy imitative competition suggests that the advanced industrial countries will orient their production in this "complex" direction. This means that the role of advanced engineering firms as a university in terms of supplying experienced engineers to related downstream industry and diffusing of specific competencies through subcontracting networks will increase.

Entrepreneurship and serendipitous discovery

There are few examples of radically new establishments in the engineering industry, compared to the C&C industry. It is interesting to speculate on the reasons for this, as many new technologies have been based on technologies developed in advanced engineering firms and many attempts have been made to commercialise defence industry technologies. One reason may be a conservative, non-entrepreneurial culture in large engineering firms and the large-scale nature of technology developed there. However, the Swedish computer industry began at Saab (the Swedish aircraft and automobile producer) in the early 1960s and was successfully developed. It effectively failed when incorporated into a large-scale, misconceived strategic venture into business information systems by Ericsson (Eliasson, 1996*a*, pp. 196 *et passim*). Ericsson, then, with some good luck, obtained sophisticated digital mobile telephone technology from its military aircraft electronics and moved rapidly to become the big player in this market.

As a second generation spillover, Ericsson military aircraft technology was used successfully for telephone systems control, which is now (together with Hewlett Packard) an operation with 1 000 employees in Sweden. Aircraft engines are another spinoff that would not have occurred without the presence of a military aircraft industry in Sweden; Volvo Aero is now a global competitor in advanced aircraft engine components. There is a third generation of spinoffs in the form of a global aircraft engine modernisation and maintenance company (Volvo Aero Engine Services) and a separate hydraulic engine operation (VOAC).

Kockum's offshore systems

Kockum is an old Swedish shipyard which has had a separate submarine division for many years. With the markets for big tankers and defence products gone or very slow, Kockum has been attempting to branch out into sophisticated civilian production based on its submarine technologies. Five of these have been important: deep-sea materials know-how; modularised production technology developed to achieve cost-efficient manufacturing, maintenance and modernisation, design of durable systems; engineering and computational know-how, systems integration and co-ordination technology (integrated production, as in the aircraft industry). Its offshore marine products – floating platforms (rigs) and vessels for drilling and operations, undersea processing equipment and connecting and remote control devices – derive from Kockum's submarine activity, complemented by externally acquired technology. They currently generate some SEK 600-700 million in sales, compared with Kockum's total sales (including submarines and military surface vessels) of SEK 2.5 billion.

Processing equipment for offshore products is operated at depths of up to 1 500 m (almost a mile) and requires materials properties similar to those required for submarines. Materials have to withstand tension, stretching and shocks, without being too heavy. They have to be easy to bend, straighten and weld. In short, they have to accommodate the particular production conditions of offshore marine products. Above all, users have to know how to specify the materials properties for each application. Kockum has sophisticated experience, gained from its production of submarines, in specifying desired materials properties for producers.

The Kockum offshore activity is very much a design and engineering one. Only specialised components are manufactured in-house, such as turrets that connect the vessel or the platform to undersea equipment. All the necessary component and user technologies were available at Kockum. To enter this new field, Kockum had to work intimately with oil companies (their main customers) and acquire new complementary technologies externally. There is a strong tendency to move production equipment down to the seabed, where lower pressure is needed to bring oil up to the seabed.

Processing oil 1 500 m below sea level is, however, not easy. Materials have to withstand extreme pressures and not corrode. The most difficult aspect is that everything is remotely controlled, since people cannot work at that depth. Hoses have to be fitted remotely, caps removed and put back, and turrets fitted. Equipment has to be lifted up and down for maintenance, etc. Remotely operated vehicles (ROVs) are used to do some of the jobs, and the technology used partly derives from torpedo development and manufacturing at Bofors, now a Bofors Underwater Systems division, which has acquired the Sea Owl, a remotely controlled minisubmarine once developed by Saab.

New industries entering production

Health care

The health care industry is, of course, an old one, but its current technological and commercial development points to a new one. The health care industry is thought of as consisting of hospital care, pharmaceuticals, medical instruments and laboratory equipment and biotechnology. Care has traditionally been seen as a public responsibility, but the United States is a clear exception, and care in European countries is beginning to develop into a profit-driven industry as well. Pharmaceuticals constitute a technological input in care services, often replacing hospital care, and the biotechnology industry is increasingly a technology supplier to the pharmaceutical industry. Similarly, medical instruments are a technological input in care services that increasingly involve significant privatisation and reorganisation of care. Typical illustrations are the growth of outsourced private laser-based eye surgery and dialysis clinics that keep the patients out of costly hospital care.

Throughout, health care is an industry that uses intensively highly educated labour with research experience. For hospital care this is so almost by definition, as in the pharmaceutical industry, but biotechnology is perhaps the only really science-funded industry which has been created around university research labs, with university researchers forming closely knit teams as new firms (Eliasson and Eliasson, 1996).

The Swedish health care industry is a competence bloc with great industrial potential (Eliasson, 1997*c*). There are extremely competent customers (hospitals) and hospital care, pharmaceuticals, biotechnology and medical instruments are very advanced. In terms of its industrial potential, however, it suffers from two problems. One, it lacks a broad and competent venture capital industry to support the selection of commercially viable projects, and two, the core part of the industry is solidly grounded in the public sector, and there is great internal reluctance to turn good ideas into profit-making ventures. Without a radical change in mentality and significant privatisation of the care sector (Eliasson, 1997*b*), the industry will not reach its potential. It is interesting to note that the most successful commercialisation of health care technology is occurring where Swedish industry shows a strong competitive advantage, namely at the intersection of health care and mechanical engineering, in medical instruments and laboratory equipment. Both Gambro (now Incentive), specialising in dialysis equipment and treatment, and Elekta, specialising in radiation brain surgery, are making inroads into the care market by building specialised private clinics. The public hospital care sector does not exhibit a corresponding interest in outsourcing part of its production. The sector's "technical" competence is advanced but critical commercial competencies are lacking, thus slowing the transformation of the technological potential of the health care sector in Sweden into a new industry.

Biotechnology industry – a pure science-founded industry

The biotechnology and health care industries are the only industries of any size founded directly in academic labs (Eliasson and Eliasson, 1996; 1997). Biotechnology is an old industry (*e.g.* beer and wine making). In its modern form, it is based on three fundamental scientific breakthroughs: recombinant DNA technology or genetic engineering, the hybridoma technique for constructing antibodies and protein engineering. Practically all of the new biotechnology industry has been established as a new firm formed around a discovery of a group of researchers led by an academic "star", a well-known academic with many publications (Zucker and Darby, 1996). Participating academics may well become rich. An econometric study found that a research focus on human genetics tends to shorten the stay of a star academic at the university (Zucker *et al.*, 1997). The star scientist also moves faster to establish a firm, the more nearby scientists have successfully done the same thing.

KaroBio: a biotechnology company internalising several functions of a competence bloc or a science park

KaroBio, a recently founded (1987) Swedish biotechnology company, illustrates how a private commercial organisation internalises several functions of a competence bloc (Eliasson and Eliasson, 1997). Despite very large R&D investments, the big pharmaceutical companies have been notoriously unsuccessful in creating innovative new substances. Small pharmaceutical or biotechnology labs are much more innovative but lack financial resources, notably in Europe, where venture capital markets are thin. University labs, in addition, lack the innovative and entrepreneurial spirit and experience to realise the commercial potential of their work. KaroBio has established itself as an intermediary between the small business or university lab and the big pharmaceutical companies. It takes on (within the narrow range of its specialities and technologies) the task of identifying and helping to screen potential substances and identify promising candidates for resource-intensive clinical testing in a large pharmaceutical company. In one sense, KaroBio performs a task that a science park might very well take on.

Recycling of super-cooled helium: an academic spillover in the engineering and medical instrument industries

Super-cooled helium (close to the absolute freezing point) is an expensive coolant used to create very strong magnetic fields and thus obtain very clear medical imaging pictures. The powerful magnetic field shakes the hydrogen atoms in the body, and when the field is stopped, the decay of the vibration of the hydrogen atoms can be measured. For this very complicated technology, the magnets have to be super-cooled to achieve sufficiently strong magnetic fields.

However, the possibility of maintaining expensive super-cooled helium in a closed recycling system had been considered unlikely. In 1988, a young Massachusetts Institute of Technology (MIT) PhD, on the basis of his thesis, started a company to achieve this. This young entrepreneur comes from an entrepreneurial family, and had taken his master's degree at the MIT Department of Cryogenetics. He was encouraged to undertake the PhD, which he did, on the understanding that his thesis project would be oriented towards an industrial application, the recycling of frozen helium. In 1988, he realised that he had a product in his thesis work. Thanks to his thesis director's connection with General Electric, together with Siemens, the big name in superconductive magnetic imaging, and the MIT reputation, the licensing office at MIT, which helps students to start firms, managed to get some venture capitalists interested. Following a seed grant from the US Small Business Administration in 1988, the young entrepreneur obtained half a million dollars plus venture funding in 1989. In early 1991, the company had a "working proof of concepts" and more venture capital soon arrived.

In 1993, the first prototype was ready. Government venture funding was, however, considered too slow to keep imitators behind. More private venture capital was secured, and by 1995 demand for the new product was running ahead of supply. The inventor/entrepreneur owned less and less of the firm, since venture investors get equity, but the value of what he owns has increased significantly. When interviewed in 1995, he thought his entrepreneurial role would soon be over. He would not necessarily stay on to take the project to industrial-scale production. If the price was right he would sell. In 1995, the company employed very few people. Despite its technological complexity (the closed recycling system), most manufacturing work can be subcontracted. Only assembly takes place at the firm, and, surprisingly, the welding, the quality of which is very critical for product functions.

Computer and communications industry: the paradoxical case of indigenous industrial creation through new establishment in a typical intelligence industry

One may point to several early originating sources of the C&C industry, some of which may have an academic origin, but most of which originated in the US defence industry. Bell Laboratories is a semi-academic institution where a team headed by William Shockley developed the transistor in 1947. Jay Forester from MIT designed the magnetic core memory in 1953. William Shockley from MIT and Bell Labs founded Shockley Semiconductor Laboratories in Palo Alto in 1955, which became the seedbed for Fairchild Semiconductor (1959), which in turn became the seedbed for a sequence of other establishments, including Intel (1968). On the whole, however, the entire US information and communications technology

(ICT) industry, as it now looks, is the result of indigenous new firm establishment around advanced industrial firms (Eliasson, 1996*a*), greatly facilitated by the selective supply of young, well-educated talent from elite universities, first MIT and Harvard, then Stanford University and finally Silicon Valley itself.

A particularly interesting observation concerns the change in competent customer input. As the role of defence industry diminished and the entire industry "fragmented" into a complex of specialist developers and producers, sophisticated and competent customers have increasingly become indigenous to the industry. While the industrial origin is fairly obvious, the fairly low intensity of PhD level staff with research experience in this industry is surprising (Eliasson, 1994*c*; 1996*d*). Particular talent appears to be more important than education; although most firms believed that PhDs represented a higher talent group, this was not sufficient. PhDs were recruited mostly in areas where radically new technology was being introduced. For instance, the development of parallel computing required innovative talent in mathematics and computer science, a quality normally only found at PhD level. It is paradoxical that the most academic and abstract of all intelligence industries appears to make relatively little use of highly educated people with research experience (Eliasson, 1996*d*).

Infrastructure production

The financial services and education industries make generic inputs into other production and are partly in the public, non-market domain. The education industry is traditionally seen as an infrastructure industry. The financial services industry has also been subjected to strong incentives to break out of its public constraints.

Financial services industry

Financial services industries, like C&C industries, are rapidly expanding, and, during the last decade, financial technology has exercised a profound influence on the local, national and world economies. "Financial technology" operates through the economy's resource allocation mechanisms and draws on two critical sources: the C&C industry and academia. The merging of computing and communications into the C&C industry (fifth-generation computing) (Eliasson, 1996*a*) has been particularly important to the global influence of the financial services industry and its related technology development.

Academics have been instrumental in financial product development, notably portfolio management, trading in risks and derivatives. The entire securitisation of the global financial services industry (Day *et al.*, 1993) is marked by academic finance research, and several of its representatives have received the Nobel prize in economics. The first round of academic "discoveries" occurred in the 1950s and early 1960s. Markowitz (1952), Modigliani and Miller (1958) and Sharpe (1964) formulated the portfolio, asset pricing and risk assessment theories, respectively. When Black and Scholes (1973) and Merton (1973) developed a pricing formula for an option at a given level of risk, the very foundation for the derivatives market had been laid. These theories were rapidly turned into new financial products which, when combined with modern C&C technology, notably in the 1980s, dramatically changed the industrial world's financial system, and the rest of the economy with it, radically redefining and reducing the roles of politically elected policy makers.

Products traded in these markets are pure abstractions ("algorithms"), some of which have required developing very innovative mathematics and the recent integration of computing and communications technology to exercise real economic influence. The product range is rapidly expanding in even more sophisticated directions, further undermining the monetary sovereignty of the national state.

The education and research industry

No industry, of course, is as academically founded as the education and research industry itself. In the post-war period, universities have become an increasingly important economic force, not least as a filter of talent for the economy. Significant elements of its past, non-innovative orientation, however, still pervade the academic community (Eliasson, 1994*a*; 1994*b*). Reorganising this largely protected industry to serve the needs of new types of production is obviously no easy task. Internal resistance will be strong. The need for new products, restructuring and new technology is strong in light of its future importance.

Education at all levels suffers from a lack of contact with the markets it is increasingly expected to serve. This is typical of industries protected from competition and is usually reflected in the absence of the experimental product development that is associated with commercial production subject to technological competition. Some of the protection is provided by regulators who essentially have shifted "product development" to the national policy level, resulting in an even greater alienation of the system from its ultimate customers. The industry is, therefore, deficient in the market competence that it will increasingly need in the future.

The most serious effects of this absence of competence will show up in secondary education in many industrial countries where a supply of well-educated young people, intellectually equipped for efficient lifelong learning, is becoming increasingly important for future industrial development (Eliasson, 1994*b*). Lacking these, and suffering from poorly functioning labour markets, ill-equipped to filter and allocate human capital and talent (Eliasson, 1994*c*), advanced economies may rapidly lose their previously privileged position.

The universities carry important responsibilities for supplying educated and talented people, research results and university entrepreneurs. The first task has always been dominant and will continue to be. The second is, however, becoming increasingly important, and the third, by its very nature, often clashes with old university traditions.

Education policy has traditionally assumed that it is sufficient to increase resources to institutions of higher education and they will turn out more of the same to the benefit of production. With increasing numbers of students taking jobs in industry, rather than in public services or teaching and research, the old product specification of university education is no longer adequate. Here, engineering and vocational institutes here have an advantage over traditional universities, since they do not suffer from old traditions. Their students also get preferential treatment in industry recruiting (Eliasson, 1997*b*).

The new types of industries emerging in very advanced countries (like the United States) obviously need highly educated people with research experience, specifically rather young people who are not too steeped in traditional academic values (Eliasson, 1996*d*).

The university industry, furthermore, has to maintain a much broader range of academic and potential industrial competencies than the corresponding industrial base, particularly in small industrial nations. Otherwise, many talented students with academic degrees in fields not directly useful to industry will have difficulties finding good jobs, owing to normally conservative recruiting practices in mature industries, a practice that works against the long-run development of local industry (Eliasson, 1994*a*; 1997*a*). In general, furthermore, these recruitment practices, as well as the general difficulty of assessing talent prior to a test period, mean that talented students will enter the job market at inappropriately low positions.

To exploit effectively the great talent and knowledge potential in the university community, entrepreneurship must be radically increased around institutions of higher education. This is even more important in European economies with poorly functioning labour markets (Eliasson, 1994*a*, *b*; 1996*d*) where many students risk being stranded in inappropriate jobs.

Bridges between technological innovation and economic growth

The previous discussion has made it clear that if the many new technologies are to contribute to industrial competitiveness and economic growth, many bridges have to be built. Some do not exist, some cover the internal structures of firms, some bridge different markets. The range of choices to be made is vast and extremely complex. Project selection processes are largely experimental and the industrial landscape will be littered with failed projects, but this is the cost of finding some winners. The competence bloc theory goes part of the way towards understanding innovative activity and economic growth, but understanding the efficient organisation of the experimentally organised market economy is at least as important. The final step is to look at the macroeconomic level, using the conceptual structure of the

Swedish firm-based macroeconomic model (Eliasson, 1977; 1985; 1991) to illustrate the principles involved. Without going into detail, this highly non-linear model views macroeconomic growth as generated by competitive selection among firms by way of the four growth mechanisms: entry, reorganisation, rationalisation and exit (Eliasson, 1996*c*). The quality of the selection is determined by the quality of the actors in the competence bloc.

The final questions here are: Under what circumstances will this selection be radically innovative, leading to the formation of new industries like C&C and biotechnology, or conservative, leading to the gradual improvement of existing industrial structures (in engineering, for instance)? How can success in some industrial activities avoid leading to long-run technological lock-in to inferior structures?

The argument here is that radically new industry formation is needed to move mature industrial economies onto long-run growth paths that will maintain their relative wealth positions, that this radically new industry formation occurs through a viable entry and a forced exit process, and that this will only occur if all the actors of the competence bloc and supporting incentives are present to ensure competition and the selection of potential winners.

The first conclusion to be drawn from the above discussion is that the choice process should be pluralistic and distributed over the entire competence bloc. No single actor is in intellectual control of the whole or should claim to be. Given the immense complexity facing innovating firms and entrepreneurs, any attempt to centralise the choice decisions is highly likely to lead to a mistake or, if it happens to be successful, to be conservative. Hence, the most important task of a policy initiative such as a science park is to support pluralism in the competence bloc. This does not mean supporting the creation of more technologies, but rather making sure that all actors and the whole range of competencies needed to commercialise existing technologies are present. The general lack of competent venture capital has been pointed out.

The role of the science park will be quite different in an advanced industrial or an industrialising economy. Catching up by introducing technology already applied in an advanced economy (the Hsinchy industrial park in Chinese Taipei; see Larson *et al.*, 1997) is fundamentally different from creating radically new technology, the distinctive attribute of Silicon Valley. Europe lies somewhere in between. With some exceptions, all areas and industries in Europe are in a partial catch-up situation. The policy problem for Europe, therefore, is to support the creation and introduction of new viable technology, notably through new entry, and to import existing technology from other countries, partly by supporting foreign direct investments. Both tasks, however, place the science park in an intermediary position between innovators and the diffusion channels to users – well-functioning labour market, institutions (*e.g.* patent, copyright) and competence bloc.

All three university activities – supplying educated and talented people, research results and university entrepreneurs – have to be supported by functioning institutions that ensure property rights and by functioning competence blocs that carry the discoveries of university innovators and entrepreneurs through to establishment. The three diffusion channels have traditionally been the responsibility of government.

Silicon Valley, as a cluster of competence blocs, has excelled in all functions: in ICT (C&C) industries, through the supply of well-educated and talented students, in biotechnology, through the supply of research results, notably through university entrepreneurship (Eliasson, 1996*d*; Eliasson and Eliasson, 1997).

US universities participate in an important local placement market, often together with students and firms. There is much less of this in Europe (Eliasson, 1996*d*). Considering the importance of human capital allocation, science parks would have a role in supporting the establishment of such placement services whenever they do not exist around the university. Many US universities also have consulting offices that help potential innovators and entrepreneurs with administrative work (patent, legal consulting, etc.) and contacts with regulators, venture capitalists, etc. Stepping in as an intermediary, where such functions are inactive, is a natural task for a science or industrial park, notably to facilitate university entrepreneurship.

Conclusion

This paper has examined the creation, diffusion and application of advanced industrial technology and attempted to identify roles for the (technical) university and the science park in that process. It argues for a considerably diminished role for academic institutions as creators of new technology and a relatively greater role as a teaching and talent-filtering institution. The science or industrial park is viewed as an operational agent for policy tasks that traditionally belong to government. It does not, however, have to be a public entity. Many of its tasks might very well be private, profit-motivated activities which improve the infrastructure for a functioning growth process, notably through the entry of innovative firms.

Science and academia participate primarily as suppliers of educational services and secondarily, and perhaps increasingly, as suppliers of new technology, but only to the extent that academic research is oriented towards such goals. This requires a strong entrepreneurial reorientation of the academic community away from ingrained academic traditions. The United States, and California in particular, appears to be far ahead of the rest of the world (Saxenian, 1994; Eliasson, 1996*d*; Larson *et al.*, 1997). To succeed as a policy instrument or a catalyst for industrial competitiveness and economic growth, the science park should be less concerned with science and technology and physical facilities (buildings, etc.) and more with commercial incentives that support the transformation of research into commercial products. However, by definition and charter, they do not appear to have been asked to play that role.

NOTES

1. The competence bloc differs from Dahmén's (1950) development bloc, which is concerned with synergy in physically defined manufacturing and distribution systems, and from Carlsson *et al.*'s (1997) technological systems, which are input-determined around the use of a generic technology (a factor input like robots) in many types of production. The concept of a national system of innovation (Nelson, 1988; Lundvall, 1988 and 1992) is close to a technological system, being defined geographically and in terms of technological inputs. The innovation system approach has two not so appealing sides in that a priori it gives a central role to the policy maker and imposes a national dimension. Here, the aim is to identify, within the competence bloc, a meaningful role for the university and for the policy maker; government and the nation cannot then be the central actor by assumption. The competence bloc imposes no such prior assumptions and is closer to Marshall's notion of an industrial district (1919).
2. The literature does not distinguish clearly between innovator and entrepreneur. Here, the innovator is identified with the engineer who integrates new and old technologies into something new and unexpected, and the entrepreneur with the person who sees the commercial opportunities of some particular innovation. Von Mises (1949) is one of the few who uses that definition. It is quite another thing that the two actors often mix in practice.
3. The five generations are the vacuum tube, the transistor (invented by Bell Laboratories, 1947), the integrated circuit (invented by Texas Instruments, 1959), the microprocessor (invented by Intel, 1971, although IBM had a microprocessor for internal use in 1968-69), and the unexpected merging of computing and communications, mid-1985 (Eliasson, 1996b). The various technologies needed for the fifth generation of computing to materialise were developed within firms. These are all ex post characterisations. In the early 1980s many observers, including Japan's MITI (B*usiness Week*, 13 April 1981, p. 123), were planning to launch supercomputing and artificial intelligence as the fifth generation.
4. The transistor may be viewed as a border case.
5. This measure includes vocational and on-the-job training and a measure of foregone resources (education or training time multiplied by wages) (Kazamaki Ottersten, 1994, p. 91; Eliasson and Kazamaki Ottersten, 1994).
6. Development of the Swedish JAS-Gripen fighter plane began in 1981. The last planes are to be retired between 2030 and 2040.

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INDUSTRIAL INNOVATION AND THE CREATION AND DISSEMINATION OF KNOWLEDGE: IMPLICATIONS FOR UNIVERSITY-INDUSTRY RELATIONSHIPS

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Introduction: universities and "technology transfer"

"Technology transfer" and "industry liaison" have become the creed of policy makers, industrial strategists, and university managers only fairly recently, but research links between universities and industry have existed for a long time. In the past, however, links were largely limited to particular types of institutions, *e.g.* *Technische Hochschulen*, Land Grant Colleges, or Institutes of Technology, and to particular disciplines and programmes, such as engineering, medicine, and other applied sciences. The US is an exception. From their inception most universities had a more "practical" orientation than the European counterparts, mainly because the decentralised nature of the American higher education system focused their missions and styles on the respective needs of their local and regional environment (Rosenberg and Nelson, 1994). But now in all industrialised countries, technical and political developments are transforming the former arm's length relationship between industry and the academy into a close embrace. Given the knowledge-intensive nature of the modern economy, the general knowledge needs of society, and the diminishing time lag between research and the development of new products or processes it is argued that all parts of the university – not just applied sciences and management programmes – must become more involved in the application and active dissemination of knowledge (Lynton and Elman, 1987; Walshok, 1995).

All industrialised countries have implemented policies to enhance innovation and competitiveness through increased and intensified collaboration between universities and private companies. In the US, legislation was introduced at the beginning of the 1980s that allowed universities to patent or copyright results of federally funded research activities and market them in their own name, and permitted universities and industry to build consortia for engaging in pre-competitive research. Other policies require universities to undertake joint research projects with industrial partners in order to be eligible for federal research grants. These policies have proven to be effective in promoting collaborative research ventures and the protection and commercialisation of intellectual property (Cohen *et al.*, 1998) are now being emulated by many other countries.

For example, in Spring 1999, Canada's Expert Panel on the Commercialisation of University Research recommended that in order for university researchers to qualify for federal research funding and universities to qualify for federal support for commercialisation, universities must adopt policies require researchers to disclose all research results with commercial potential to their institution. Universities would be required to report all intellectual property emanating from federally funded research to the federal government annually, and demonstrate efforts to commercialise those results found to have innovative potential.

Likewise in Germany, where the law leaves the protection and the commercialisation of intellectual property to the individual researcher, the Hochschulrektorenkonferenz (the council of university presidents and rectors) recommended in 1997 that universities adopt institutional policies to secure intellectual property rights and take them to the market through special commercialising units.

The general concern is that much of the research and technology generated by higher education institutions is not fully exploited, or often not exploited at all. Similar initiatives have been undertaken in the United Kingdom (Howells *et al.*, 1998) and more recently in Scotland, where the Enquiry into the Commercialisation of the Academic Science and Technology Base was conducted to develop a Strategy for the Commercialisation of R&D for Scotland (Scottish Enterprise and the Royal Society of Edinburgh, 1996).

In Japan, collaboration between universities and industry was traditionally considered taboo. Strict rules existed to prevent researchers at the National Universities to from engaging in any formal co-operation with private firms. But recently both Monbusho, the Ministry for Education and Science (Monbusho, 1996*a*), and the Japanese Society for the Promotion of Science have made serious efforts to improve the co-operation between the two sectors. The Study Group on University-Industry Cupertino, set up by Monbusho in 1996, recommended far-reaching changes to university rules and infrastructures in order to permit dialogue and Cupertino with the private sector. The group pointed out that engagement by university researchers in co-operative projects with industry should be "regarded as working towards the general good of the nation" (Monbusho, 1996*b*). In the same year, the government issued a Science and Technology Basic Plan, emphasising the intensification of university – industry Cupertino as one of the keys to the nation's future.

In spite of the recent policy emphasis on university-industry relations and Cupertino, increased research links and intensified Cupertino are not without problems. The objectives, mandates, values, reward systems, cultures, and codes of practice of universities and private enterprises are different and sometimes in conflict, making communication and collaboration problematic. As already mentioned, some types of institutions – for example Technical Universities in Europe and Land Grant Colleges in the US – have less difficulties since Cupertino with industry (or agriculture) was the rationale behind their establishment and therefore an explicit part of their mandate. But many academics in traditional universities resist the idea that knowledge has an economic value and that helping to realise that value is part of the university's mission. This perspective is grounded in the idea that university education and research are "public goods", freely accessible and serving the public not private interests. It was reinforced by strict rules in many countries that made collaboration by university researchers with private firms not only morally questionable but also practically difficult, if not impossible. Japan has already been cited as an example of this tradition, which has parallels in other countries.

More recently with globalisation of markets and international competitiveness becoming major policy concerns in the OECD countries, there has been a marked shift in attitude by both governments and industry towards appreciation of the role and potential contribution of university research to industrial innovation. As mentioned, governments have eliminated many of the former hurdles to closer university – industry collaboration, and established a system of both pressures and incentives for institutions and individual faculty to engage in closer research contacts and joint projects.

Partly as a result of these policies, but partly due to their own interests and initiative, universities have opened up their research facilities and staff to industry to an unprecedented extent. At the same time, they have started to commercialise intellectual property by licensing patents and copyrights to industry. Especially in the US, where this practice has been installed for some time now, these changes have had far-reaching effects not only on the traditional organisation of universities but also on their "inner life". Generally policy makers, university administrators, and industrialists see this "second academic revolution" (Etzkowitz *et al.*, 1998; Webster and Etzkowitz, 1991) as a great success story, but many academics warn about the dangerous effects of this trend towards "academic capitalism" (Slaughter and Larry, 1997) on the integrity and principal functions of universities, research, and education.

However, the traditional functions of the research university may be changing for other reasons as well. In the past, with the exception of specialised higher education institutions and some "applied" fields, there was a relatively clear distinction and division of labour between university research and industry which concentrated on basic research with little or no regard for its usefulness and commercial application, the latter was directed at technical innovation, market share, and profit. The distinction is becoming increasingly blurred.

New technical and economic developments put into question the traditional understanding of innovation as a linear and uni-directional process moving downstream from the university research laboratory into industry and then the market. It is now recognised that there are other forms of knowledge and knowledge creation that take place outside of university laboratories and involve the complex interactions of producers and users, theory and practice, and academia and industry. There are important consequences for universities and the traditional concepts of academic research and dissemination. As universities become players in "systems of innovation", knowledge networks, and other forms of joint knowledge creation and dissemination, traditional concepts are being scrutinised and redefined.

In this article I will look at the university – industry interface from the perspective of innovation system theory, discussing the issues of organisational structures and procedural mechanisms for university-industry collaboration. Such collaboration is often discussed in terms of demand and supply of scientific and technological knowledge, or "technology push" by universities vs. "technology pull" from industry. Starting with the demand side, I explore first the question of how firms innovate and what motivates them to collaborate with universities, distinguishing both between firms of different size and different industrial sectors. In the second section, I then address the question of how universities are disposed and organised to collaborate with industry. In the framework of this paper, I can only mention briefly the problems in the university – industry interface which have given rise to critical comments from observers both from industry and academia. In the final section, I emphasise the education and learning side of the university – industry relationship.

How do firms innovate?

Firms and systems of innovation

The ability of firms to innovate – that is harness new ideas to create new or improved products or processes – depends on their innovative capability. This capability depends on the entrepreneur, as Schumpeter (1934) suggested, as well as the firm's staff and their qualifications, experience and attitudes. But it depends also on many factors outside the firm. Such factors include linkages with other firms (competitors, suppliers, clients, business services); the local research and development infrastructure (university or other research laboratories, graduate seminars, libraries, engineering bureaux, software firms, internet access); educational institutions (schools and post-secondary education and training institutions); intermediary organisations or agents that facilitate the search for and access to knowledge and information (knowledge networks, local knowledge and technology brokers); the availability of venture capital and other forms of financing; and generally a culture that values creativity, innovation, and entrepreneurship. This dependency of enterprise innovation on external factors has led to the realisation that innovation does not normally occur in isolation, but within a "system of innovation"[1] which involve a great variety of institutions, networks, linkages and relationships (Lundvall, 1992; OECD, 1992).

Also, as mentioned earlier, research has found that innovation is not the result of a linear trajectory from university laboratory to the innovative product or process. Rather, it is the result of a multi-faceted and multi-directional process with many inputs and feedback loops. In this process, scientific research sometimes plays an important role. Often though, a technical innovation will involve not new research but a particular application of a known scientific discovery or technical development, or a substantial improvement of an existing product or process. It takes a long time before fundamental advances in the sciences have an impact on industrial technical innovation (Rosenberg and Nelson, 1994). Rather than being directly research-based, innovation is a comprehensive social, communicative, and learning process involving knowledge and expertise of different kinds. Even where innovation does involve the application of original research, it also requires other knowledge inputs and learning processes as well.

Empirical research on firm-based innovation has provided valuable information and insights into the organisation of information flows, decision-making, the role of in-house R&D in knowledge creation, and the use of knowledge or information from sources outside the firm. Most large firms that build cutting-edge high-tech products employ scientists and engineers and have in-house research laboratories. In sectors such as pharmaceutical production, firms spend up to ten percent of sales on R&D. Accordingly, R&D is given high priority in such companies and is linked to design, production and marketing through highly sophisticated management and monitoring systems. Parallel to in-house R&D efforts, the firm's technology antennae investigate and monitor specific new scientific developments and technologies developed outside the company, providing the corporation's scientists, engineers, and managers with ongoing information about state-of-the-art potentially relevant research. In turn, this information serves as the basis for a process of dynamic and interactive evaluation and strategic decision-making. Regular contacts with the field's most advanced university researchers and laboratories are seen as useful in obtaining early access to basic scientific knowledge and monitoring longer-term developments. Thus such firms often participate in the corporate affiliate programmes offered by large research universities like the Massachusetts Institute of Technology or Stanford. Affiliate programmes offer corporations advance access to developments that might eventually lend themselves to commercial application. As a result of these contacts, these companies will often engage in joint research projects, hire university scientists as consultants or company researchers, or place some of their own R&D personnel into university laboratories to work with university scientists.

Little empirical research on innovation has been conducted on smaller firms (Acs and Audretch, 1990) even though many of them are no less innovative than larger firms. Innovation in small firms is significantly different than in large. Even in cutting-edge technical fields, small firms rarely have their own research laboratories, although some will have university-educated personnel. With rare exceptions, the majority of SMEs lack the resources to engage in such activities and must rely on external sources of knowledge and spill-overs from research done elsewhere. As well, although innovative in many ways, they often face problems in utilising external R&D as there is a strong link between expertise built on in-house R&D and the firm's "absorptive capacity" (Cohen and Levinthal, 1990). The latter constitutes the expertise and capacity to systematically monitor research and technological developments done elsewhere and to recognise those of potential interest and relevance, as well as the ability to actually harness and apply them. This explains why external sources of information and knowledge, such as public R&D organisations (research universities or non-university research institutes), are rarely used by smaller firms directly, rather access is usually mediated by transfer agencies, consultants, links with other firms or industrial associations, and specialised business services (Schuetze, 1998).

While firm size is an important variable for determining the nature and potential extent of university-industry relationships, other factors are also important. One is they type of industry involved. Research on scientific and technological developments shows that the role of university-based R&D is quite different in various industrial sectors. For example, the fledgling field of biotechnology was primarily developed in university labs, while computer and telecommunication technologies were largely developed by industry without the involvement of university laboratories (Eliason and Eliason, 1996). As several other studies show, such cross-differences are important. The1994 Carnegie Mellon Survey of some 1 500 R&D lab managers in the US manufacturing industry found considerable reliance on university research, prototypes, and instruments not only in high-tech industries such as semiconductors, drugs, and medical equipment but also in more mature industries such as food, petroleum, and steel. In contrast, textiles, plastic resins, metal products, and electrical equipment use much less academic R&D in their product design and production (Cohen *et al.*, 1998).

In assessing industrial demand for university-based R&D, it is also useful to distinguish different motivations for why industry might seek university collaboration (Bonnacorsi and Piccaluga, 1994). Three sets of motives seem prevalent (see Table 1). First, industry seeks linkages with university research for obtaining access to new scientific frontiers, where developments from basic research are long-term and beset with incalculable risks, and where the potential application or commercialisation is not yet entirely clear. Obtaining early stage, state-of-the-art information about scientific developments that may become commercially viable is a rational strategy (and investment) on the part of larger firms producing cutting-edge technological products.

Table 1. **Industry motivations and demand for, and forms of, university-industry collaboration**

Motivation	Forms of collaboration
Obtaining access to emerging scientific frontiers and state-of-art knowledge	– corporate affiliation programmes – consortia for pre-competitive R&D (centres of excellence)
Saving money and reducing risks through – collaborative R&D – exploiting commercially viable results of university R&D	– contract R&D – modelling and testing – use of university researchers as consultants – purchase of patents, copyrights etc.
Obtaining access to knowledge through human resources development and lifelong learning	– hiring of university graduates – internships, co-operative education placements – participation in continuing professional education and other learning opportunities

Second, firms are also motivated by the chance to save on their own resources and reduce risks by engaging in collaborative research or by commercially exploiting the results of R&D originating in university labs or the offices of university researchers. Prime examples are various forms of contract R&D, normally conducted at the university or in intermediary institutions, such as university-industry research centres and other types of institutes associated with the university in one way or another, *e.g.* the various A*n-Institute* in Germany. Frequently such collaboration takes place at the firm itself through consulting contracts with individual university researchers. These forms of collaboration are not limited to science and technology-based fields. University researchers are also involved in collaborative interchanges in other fields such as exploration of legal issues, preparation of marketing and organisational studies, and design of products and software.

Finally, firms are motivated by the opportunity to access embodied knowledge in the form of high quality personnel. The screening and recruitment of graduates is of primary importance for firms and their innovative capacity. Companies involved in joint research projects or other related activities often the hire graduate students and assistants who have worked on these projects. The majority of firms, especially smaller firms without research links, must find and screen graduates through other means, *e.g.* contacts with professors, interviews on campus, or temporary employment of students in co-operative education schemes, and so on.

Access to university continuing education opportunities is more important for some firms than others. Larger firms can take advantage of strong professional organisations that offer updating, management or marketing courses under their own auspices, often hiring university professors to teach them. Smaller firms tend to rely on industry associations, chambers of industry and trade, and proprietary (for-profit) schools as the main providers of continuing education and training. In some cases this is due to threshold inhibitions that make access to university programmes problematic for many smaller firms; more often though, it appears to relate to the perceived lack of relevance of university provided courses and programmes (Schuetze, 1998). There are a few university extension programmes aimed especially at small firms, such as the Georgia Tech Industrial Extension Service in the US (OECD, 1995), but such programmes are relatively rare.

Summing up, demand from industry for scientific and technological knowledge manifests itself in many fields. While the focus of most studies on industrial innovation is on "technology transfer" in a narrow sense, the often overlooked or neglected "teaching and learning connection" is an essential part of this relationship. In the following section, I look at the university side of university-industry relationship.

How do universities collaborate with industry?

Several developments have caused universities to change their views on the instrumental aspects of research and make attempts to collaborate more actively with private companies. One is the search for additional sources of research funding. Public sources of funding, in particular from government departments and research councils, saw a massive increase in the 1960s and 1970s but began to level off or decrease in the 1990s.[2] Important also is the change in government policy alluded to in the introduction, which actively promotes industry collaboration in a number of ways. These range from the strengthening of co-operative and transfer mechanisms inside or outside of universities, to making government funding dependent on industry participation. This policy has its origin in the increasing globalisation of foreign investment and trade and the resulting concern of governments to keep or make their industries internationally competitive (Gibbons, 1992; Slaughter and Rhoades, 1996).

But the modern university's interest in collaborating with industry surpasses the desire for additional research funding. As scientific research and technological development have become more interdependent, and their relationship more dynamic, important areas of R&D are increasingly conducted in industry rather than university labs (Eliason and Eliason, 1996). Universities no longer have a monopoly on scientific knowledge generation. In order to stay abreast of their fields, university researchers are forced to become involved not just in exchanges with their academic peers but also in networks of knowledge producers whether in the academy, in industry, or elsewhere (Schuetze, 1996*a* and 1996*b*). In consequence "academics who remain aloof from technological innovation will find themselves excluded from important peer groups – to their individual and institutional disadvantage" (Gibbons, 1992, p. 97).

University organisation and its rationale

Traditional universities are organised in particular structures, for example faculties, chairs, departments, and institutes. These structures reflect not only the division of power and tasks within the particular organisation, but also the tradition of basic and discipline-based research. There exists a highly structured division of labour and a finely tuned specialisation both between different types of institutions and within the individual university and its sub-structures that makes internal and particularly external collaborations difficult. In spite of rhetoric to the contrary, the university is neither a coherent institution nor a community of scholars, but rather "a collection of substantially autonomous individuals, loosely organised into departments or equivalent units – themselves often fragmented" (Lynton, 1996, p. 83). The frequent complaint by industrialists that "industry has problems – universities have departments' reflects this fragmentation. It indicates the difficulties if not the inability, for traditionally structured universities not only to do interdisciplinary research but also to reach out over university boundaries to work with outside organisations like private companies or industry consortia.

Academic researchers are members of their university and department but they belong, at the same time, to a discipline or a field of study. These multiple memberships "shape their work, call upon their loyalties and apportion their authorities" (Clark, 1984, p. 112). Changes in these kinds of institution occur very slowly, "with much grass-roots initiative, with persuasion and voluntary initiative rather than command, incrementally rather than grandly with changes flowing quietly over institutional boundaries, and often in highly intangible ways" (*ibid.*, p. 126). Of course, the tendency of institutional inertia does not mean that all individual academics are inflexible, even if it can probably be assumed that this organisational framework has a certain degree of influence on the mindset of those who have been successfully working in it.

Another factor which make collaboration with industry problematic from the faculty point of view is the particular conception of the nature of knowledge and ways of knowing:

> Deeply ingrained in the self-image and the attitudes of the academic world is (...) the notion that there exists a set of theories and principles – some known, some waiting to be discovered – that can be applied rigorously to well defined problems and lead to correct solution. Application in this conceptual framework is no more than the act of putting theory to use and, therefore, is not in and of itself a potential source of new knowledge. Hence the flow of knowledge is linear and unidirectional, from the locus of research to the place of application, from scholar to practitioner, teacher to student, expert to client (Lynton, 1996, p. 81).

Such a framework of "technical rationality" (Schön, 1983) is in conflict with the innovation systems approach to technical innovation, mentioned above, that sees innovation as a social process with many players, feedback-loops and multi-directional channels of communication. The traditional framework has a number of concrete practical repercussions for people working in the academy and the value and reward system that applies to them and their work. In particular, it tends to place traditional, basic research on top of the hierarchy of functions from which all other functions flow, thus classifying other forms of scholarship such as applied research as secondary (Boyer, 1990).

The hierarchical conceptualisation of "scholarship" and the adherence to a linear model of knowledge creation and flows from university lab to industrial shop floor, tends to create attitudes that see applied and industry-sponsored research as something less desirable and proper for academics to undertake. In particular in the sciences, the social sciences and the humanities, applied research carries with it an "intellectual stigma" and applied researchers in these disciplines "may lose in prestige what they gain in dollars" (Bowie, 1990, p. 211). This is in marked contrast to "applied" academic fields, notably engineering, computer sciences, and the health sciences, or emerging hybrid fields such as biotechnology, where such notions appear quite strange and where the bulk of university – industry collaboration in fact takes place.

The major impediments to academy-industry relationships result from basic differences between the two sectors. The concept and emphasis of university research, and the disciplinary basis of traditional university structures, are in conflict with the instrumental, market-based, and bottom-line oriented approach to knowledge in industry. The basic differences between the academic and industrial concepts of knowledge and knowledge creation are summarised in Table 2.

Table 2. **Industry motivations and demand for, and forms of, university-industry collaboration**

Industry	Academy
Realisation of Economic Value	Creation of Intellectual Value
Industrial Applicability	Scientific Credibility
Market Oriented	Mission Oriented
Inductive or Synthetic	Deductive or Analytic
Problem oriented (Trans-Disciplinary)	Disciplinary
Telesis (goal-orientation)	Serendipitous/curiosity driven
Commitment to Schedules	No time constraints
Private Good (Proprietary)	Public Good

Source: Adapted from Tomiura (1997).

The differences in basic missions, objectives, values and attitudes help to explain why industry and the academy are "uneasy partners" (Cohen *et al.*, 1998).

Because of the slow path of change in the traditional organisation of the university, as well as in the attitudes and values that prevail in a large part of the academy, institutions have often created organisational units outside the traditional structures in order to facilitate communication and collaboration with industry. Examples of such new organisational structures and mechanisms are industrial research chairs, associated institutes, *An-Institute* in Germany, science parks, intellectual property, and university-industry liaison offices. Parallel to such university units, governments have also set up or sponsored structures outside universities, though closely linked to them, such as the institutes of the Fraunhofer Society for Applied Research in Germany, the Networks of Centres of Excellence in Canada,[3] and the Science and Technology Centres and the university-industry R&D centres in the US.

University – industry collaboration and the inner life of the university

"The relationship between academic research and industrial R&D has come under intensive scrutiny (...). Academic research is perceived to be both too distant from the needs of industry and, for those few industries where its relevance is apparent, too close to industry" (Cohen *et al.*, 1998, p. 171). Critics from within the university claim that such a close relationship compromises the principal missions of the university – teaching and research – and that the commercialisation of university research produces important conflicts of interest for university researchers with negative consequences for their scientific objectivity and commitment to students. Studies have shown that in many cases industry-sponsored research requires investigators to forego or postpone publication of the methodology and findings of their research (*ibid.*). It is claimed therefore that while individual companies profit from these partnerships, the creation of knowledge through scientific research suffers in the long run (Slaughter and Larry, 1997; Cohen *et al.*, 1998; Schuetze, 1999).

This topic cannot be discussed with the detail it deserves in the framework of this paper, however this brief mention should not belie its importance.

The dilemma that the commercialisation of university research generates for large research universities has been described by the former president of Stanford University:

> A form of entrepreneurship has now become firmly rooted in academic science – not in just a few disciplines, but across the board. (…). The ethical ramifications present complex tests – for university decision-makers no less than for individual faculty members. Defending the university's balanced interest in work without commercial application; protecting students and junior colleagues from inherently coercive situations; securing freedom of access and of publication; these are just a few of the challenges that now regularly present themselves. It has put a strongly utilitarian cast on the role of the universities (Kennedy, 1996, p. S. 111).

But neither Kennedy nor other critics of the present situation in the US favour a return of universities into the ivory tower. Rather, they support collaborations with industry under the condition that these are balanced and respect the specific nature of university research and teaching. Richard Nelson (1996) has summarised this position:

> A shift in emphasis of university research towards more extensive connections with the need of civilian industry can benefit industry and the university if it is done the right way. That way (…) is to respect the division of labour between universities and industry that has grown up with the development of the engineering disciplines and the applied sciences, rather than one that attempts to draw universities deeply into a world in which decisions need to be made with respect to commercial criteria. There is no reason to believe that universities will function well in such an environment, and good reason to believe that such an environment will do damage to the legitimate functions of universities (Nelson, 1996, p. S. 228).

Innovation, education and learning

Technology transfer is often seen as unrelated to other university activities, especially teaching and learning. There is sometimes recognition that the transfer process frequently demands some kind of "technology software", *i.e.* additional knowledge or information that are disembodied from the technological information or artefact. To be sure, specific educational activities such as technical presentations, workshops, seminars, and demonstration projects are recognised as elements of innovation-related knowledge transfer and learning. But on the whole, education and learning are normally not seen as part and parcel of a more comprehensive process of knowledge transfer.

If however, as Lundvall (1992) and others argue, "systems of innovation" must be primarily considered as "systems of learning" then innovation occurs primarily through the dissemination of knowledge – teaching and learning – that universities contribute to industrial innovation and economic development. In the words of the former president of John Hopkins University, one of the leading US research universities, "universities remain primarily teaching institutions, and their chief role is to develop and train human talent", their chief linkage with industry being "the pool of talent which the universities both harbour and produce" (Muller, 1984, p. 25).

Industry is not just involved in the hiring of the "end product" of that educational process but also in the process itself. As it is in industry's interest to hire graduates who possess both generic knowledge and attitudes, and job-relevant know-how and particular skills, they try to exercise influence on what students learn. One example is the influence on curriculum design and content in most of the applied and professional fields through industry membership in institutional curriculum committees, a form of feedback on the requirements of practice and on emerging fields of specialisation. Another example is the impact of national or regional professional associations on the academic curriculum by defining the requirements and criteria for licensing and certification. Individual firms also exercise influence, albeit indirect, by providing opportunities for practical training (internships, co-operative education placements, practice, and the like) which, in many professional and applied fields, is required as part of the academic programme. While such industry placements provide students with the opportunity to apply theoretical knowledge to practical problems, for companies they mean contacts with faculty and opportunities for feed-back concerning the relevance of the academic curriculum.

Besides the upgrading of a competent workforce through the recruitment of new graduates, a second way to gain access to scientific and technological knowledge is through participation in continuing education and training activities – an extension of the original mandate of higher education to provide opportunities for lifelong learning for graduates. Because of the increasingly rapid advancement of the sciences and technological change, professionals – especially of the health, natural and applied sciences – need to periodically upgrade and extend their knowledge base in order to keep abreast of changes (see for example MIT, 1982). While this need for continuous learning is a general characteristic of the "knowledge society" and the "knowledge economy", it is also essential for the process of "technology transfer" firms must develop or maintain their capacity to absorb new information and knowledge to successfully appropriate and apply knowledge from external sources. In this general sense, is clear that continuous learning opportunities are not confined to classroom-based teaching activities but occur in a multitude of forms. For example, presentations by university researchers on particular problems, trends or developments; participation in academic conferences or in meetings of professional societies; workshops or seminars; joint development projects; and formal or informal exchanges between university researchers and industry professionals and managers are forms of knowledge transfer and learning that contribute to that absorptive capacity.

Knowledge needs and knowledge resources

In applying such a comprehensive view of what universities contribute to industrial innovation and in concentrating not only on the technical but also the cultural and structural elements that tend to impede efficient university – industry relations, it is useful to identify the organisational preconditions and consequences of an efficient relationship. This cannot be limited to the question of how university research can be made more relevant and accessible to industry, but must also include how the university's teaching and service functions can be organised to contribute to industrial innovation.

While traditional channels of knowledge extension and dissemination were primarily teaching and scholarly publications, the massive increase and rapid turnover of knowledge requires new forms of extension and dissemination. This entails new objectives and focus and new audiences for university teaching as well as better mechanisms for disseminating new knowledge to increasingly large and diverse publics (Lynton, 1996).

Walshok (1995) distinguishes three types of knowledge flows, namely education and training, the synthesis of knowledge from different disciplinary fields, and knowledge diffusion, transfer and exchange. (For a comparison of knowledge needs and university-based knowledge resources see Table 3.)

Starting with the first of these knowledge needs, the provision of continuing education and other organised learning opportunities for professionals working in the private sector is clearly under-developed in universities. An example is professional continuing education for engineers, a group that is centrally in the (technical) innovation process (OECD, 1992) and whose competence is of crucial importance. Engineers are employed in practically all industry and service sectors that deal with technological products and processes, not just in high-tech firms. Consulting engineers play a strategic role in the development of a nation's infrastructure, resources, and industrial base as well in the maintenance and protection of the environment.)

The fast turnover of scientific and technical knowledge and the resulting need to keep pace with advances in the applied sciences and with engineering systems of growing complexity is becoming a con-

Table 3. **Knowledge needs and university-based knowledge resources**

Knowledge needs	Knowledge resources
Professional/work-related updates	Professional continuing education Developmental continuing education in new knowledge areas or interdisciplinary fields Skill training in new technical fields in response to, changing or emerging job requirements, such as laser technology in manufacturing; new diagnosis/technologies in medicine; new paradigms in fields such as biotechnology Training for crossover skills, such as management skills for engineers
Knowledge brokering across fields and industries	Provision of interdisciplinary knowledge and skills to practitioners and problem solvers in technical, social, economic, and community contexts Provision of assistance on complex interdisciplinary problems such as regional economic development or technology assessment Interactions between researchers and practitioners in areas of research-affected practice undergoing rapid changes
Knowledge updates through knowledge diffusion, transfer, and exchange	Provision of science based information and knowledge: – to consumers and users of basic research interested in the application of research findings for new services, processes, or products – to constituencies interested in new business formation, such as venture capitalists, bankers, new entrepreneurs – to professionals and lay people whose work requires technological literacy, such as journalists, managers, environmental experts, etc.

Source: Based on Walshok (1995), Table 4.2.

cern of engineering firms and many of the advanced technology firms where engineers are employed. New scientific and technical knowledge is generated at such a rapid pace that old knowledge becomes obsolete over increasingly short time spans. Thus the traditional concept and principal method of one-time, front-end engineering education is no longer sufficient to provide an adequate foundation for a lifetime of professional engineering work. The demand for highly competent, creative, and versatile engineers is intensifying as a result of the rapid growth of knowledge-intensive industries and increasing competition for national and international markets. It cannot be met by replacing engineers possessing an obsolete knowledge base with new graduates. For the last decade or two major policy bodies have called for greater efforts by universities in accommodating the demand for continuing professional education. This call has also come from some universities or departments. For example, a study by MIT's Electrical Engineering Department found that given the rapid technological developments in the field, the half-life of their graduates' knowledge was approximately two years. As a consequence, the department suggested a model of lifelong co-operative education for engineers, with close Cupertino between engineering schools, industry and professional associations (MIT, 1982) – a recommendation that was however not implemented.

Neither have these calls had any major effects on universities elsewhere. In most OECD countries, professional continuing education is still a minor activity on most university campuses (OECD, 1995), organised by separate continuing education units rather than by the mainstream departments. Engineering is no exception. Even if courses are offered, firms often complain that they don't suit their needs as teaching tends to be excessively theory-led and most professors have little industry experience (Lynton, 1996). Moreover, in most universities, continuing education is rarely linked to technology transfer or other industrial liaison activities. In almost all institutions, continuing education and technology transfer are the responsibility of separate and disconnected units, reporting to different parts of the university management.

There are also problems with responding to the second type of knowledge needs, knowledge brokering across fields. They are largely due to the discipline-based nature of most university research. To be sure, there are pockets of interdisciplinary – for example economics departments co-operating in management research, commerce departments offering courses in technology management, education departments doing research on innovation and learning at the enterprise level – but on the whole interdisciplinary is precariously established in universities. Collaboration among social, natural, and applied scientists is rare. Even where interdisciplinary is embraced in principle, departmental structures and disciplinary boundaries remain important barriers that new "hybrid" organisational units find difficult to overcome (Lynton, 1996; Walshok, 1995). Industry, and professional groups that would benefit from such problem-oriented research and teaching, are therefore often frustrated "by the logics of discipline, expertise, and professionalised disorder" (Clark, 1983).

Finally, responding to the need for knowledge up-dating through knowledge diffusion, transfer and exchange, would require more active outreach and liaison activities, meaning that universities, departments and individual researchers would need to interact more actively with enterprises. However, ongoing contact with firms is a time-consuming task at odds with researchers' other academic duties and there is relatively little academic recognition or incentive for faculty to do this (Walshok, 1995; Lynton and Elman, 1987).

Conclusion

Technology transfer as it has been conventionally understood is only one part of a larger system of knowledge creation and application, involving many forms of communication and interaction between university and community. Learning is central to innovation – in fact "systems of innovation" are "learning systems". As long as advancement of knowledge through teaching and learning is a central responsibility of universities, knowledge transfer must involve opportunities for learning of all kinds – technical, organisational, managerial, cultural. Only a few universities think of co-operative research and organised learning as twin activities. A few more are involved as active partners in regional or national networks. But while commercialisation of research and university – industry research linkages have massively grown over the last decade, recognition by most universities that they must engage in more learning activities has developed relatively slowly and remains a challenge for the future.

NOTES

1. Similar concepts have been suggested by other authors such as "techno-infrastructure", "competence blocks" (Eliasson and Eliason, 1996).
2. Within the group of industrialized countries Japan has been an exception to this general trend. An example is the Japanese Society for the Promotion of Science (JSPS) whose budget doubled between 1994 and 1997 (JSPS, 1997).
3. For further reference on Canada, see Doutriaux and Barker (1996).

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THE CHANGING PARADIGM OF KNOWLEDGE IN HEALTH CARE: IMPLICATIONS OF EVOLUTIONARY EXPERIENCE IN THE UNITED STATES

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Introduction

Knowledge has unquestionably been one of the most valuable resources in the health sector of the United States' economy during the 20th century. Enviable economic returns have been earned by the physicians, pharmaceutical companies, insurance carriers, and other economic units which have controlled the know-how required to diagnose a disease, manufacture a prescription drug, sell a health plan, or otherwise manage patients' access to health care resources. Examination-based certificates to provide specific health services, minimum educational requirements for professional practice, state insurance licenses, and federal patents to protect returns on investments in new drug development are examples of formal mechanisms based on the existence of identifiable and organised knowledge bases in health care.

The knowledge-based relationship between professional power and economic returns has been stable for so long that casual observers could be tempted to extrapolate their understanding of it into the future. However, a fresh inquiry into the nature of the relationship strongly suggests that its 20th century foundations are rapidly crumbling. The corresponding situation of health care knowledge in the early 21st century is likely to be very different. An historian's explanation of the production, mediation, and use of knowledge in the health sector over the past 100 years is essential for those who want to understand the changes that are taking place. However, a futurist perspective is just as important for those who need to understand the evolving relationships and their implications.

This paper is based on the premise that the relationships of health care and knowledge in the United States are being radically transformed by information technology, privatised reform, competitive market forces, consumer empowerment, and other forces that were not prevalent in the past century. It describes and contrasts proposed understandings of old relationships and new ones that are developing to replace them. Above all, it seeks to initiate a dialogue that will help health professionals and resource allocators (*e.g.* managers of health care organisations, public policy makers, purchasers of health plans) to examine the implications of their decisions in the context of new and unprecedented circumstances.

Evolution in the meaning of knowledge

The dynamism described here goes beyond the changes expected in production, mediation, and use of traditional knowledge. The meaning of health care knowledge itself is changing. Positing simultaneous evolution in both the meaning and processes of knowledge requires a complex analysis, but investigating health care knowledge with a univariate model runs the serious risk of yielding irrelevant or erroneous conclusions.

In other words, the issue is not simply trying to understand new ways to process the same old knowledge or even the same old concept of knowledge. Rather, the focus of inquiry must be how new processes will produce new understanding of the realm of possibilities for human health and medical care. An introductory review of basic definitions will build a case for a two-factor dynamic analysis and show why changes in the meaning and content of knowledge are potentially just as important as changes in its production, mediation, and use.

Knowledge is often and usefully defined as the third tier in a conceptual hierarchy (Chapter 2 in Cleveland, 1985). The first tier of the structure is *data*, the raw figures that describe an observation or quantify the workings of a system. Data by themselves do not tell us anything useful; they need to be organised into meaningful categories to produce the hierarchy's second tier, *information*. Data do not start to have meaning and impart information until they are transformed into measures of central tendency (*e.g.* mean, median, mode) and measures of dispersion (*e.g.* deviation, variance) that allow standardised descriptions and comparisons of what is of interest. The next step is *knowledge*, the purposeful application of information to decision-making. The fourth and final tier of the conventional hierarchy is *wisdom*, the art of consistently making good decisions based on experience. That lofty topic will be left to the philosophers.

Knowledge as the measure of well-informed health care decisions is certainly a timely issue because modern industrial countries are all asking how their medical care delivery systems could be improved by better knowledge. Questions abound. What new knowledge would allow us to produce a healthier population? What do we need to know to reduce the costs of producing health services? How can information technology be used to improve the quality of care? Good answers to these questions are not so common. As shown by the universality of current efforts at health reform, every modern industrial country wants to know how to fulfil the political imperative of spending less on health care without failing to meet the social imperative of maintaining access and quality (see Raffel, 1997).

Consequently, the most important measure of the processes of producing, mediating, and using knowledge in the future might be the extent to which these processes lead to better (*i.e.* more knowledgeable) decisions about allocating health resources. From an economic viewpoint, the processes have no value if they do not ultimately yield tangible improvements in the delivery of health care services. We will have gained nothing if the processes of production, mediation and use only efficiently produce useless knowledge.

A desirable advance would be process changes that give fair value to *negative knowledge*, that is, knowing what *not* to do. The US health care knowledge base has long been biased against reporting research that accepts the null hypothesis (*i.e.* failed to find a statistically significant relationship between an experimental effect and an observed outcome). We have suffered from the publication bias perpetuated by journal editors who only accept articles that "prove" the existence of a relationship. We could benefit at least as much from the publication of good studies that demonstrate no relationship between a medical intervention or health policy and a desired outcome. A good policy on the production, dissemination and use of knowledge would equally respect positive and negative knowledge.

A proper knowledge policy would also impose stringent quality standards on the processes that create data and turn them into information and knowledge. Sadly, the overall quality of the existing knowledge base is abysmal.* The majority of clinical and policy studies published in the United States are seriously flawed by poor data, bad experimental methodology, political power and/or inappropriate statistical analysis. Even the most prestigious journals are often (but not always) guilty of imparting considerable misinformation. Erroneous information is likely to produce flawed knowledge, so formal concern

* A detailed defence of this controversial position is a central theme of Bauer (1996). The author has used this as a text for several years in teaching statistics and research methods at the Medical School of the University of Wisconsin-Madison, and nearly all the practising physicians in the classes concurred in a generally low assessment of the quality of the existing knowledge base in health care. The author has also successfully defended this position more than a dozen times as an expert witness in civil litigation. US federal courts have independently come to the same conclusion as the result of challenges to expert testimony presented in the famous product liability case about breast implants, *Daubert vs. Dow Corning*. Federal courts now scrutinise expert testimony with *Daubert* quality standards which are much stricter than the requirements for publication in a typical health care journal.

with the quality of the components of knowledge needs to be elevated to the level of policy if we are to move forward by design rather than luck.

Formalised attention to the quality of data might lead to the creation of a system for rating the components of knowledge on a multi-dimensional scale. We currently lack a qualitative instrument that makes it possible to decide whether existing data and information are worthy of attention. Parameters to be considered for inclusion in a rating system might include:

- *Scope* of knowledge: the relative degree of knowledge about a topic, ranging from virtually none to almost complete.
- *Age* of knowledge: the currency of the knowledge, from outdated to up-to-date.
- *Cost/benefit* ratio of knowledge: the value of the knowledge in use relative to the cost of acquiring it.
- *Reliability* of knowledge: the accuracy with which the underlying data measure the object of interest.
- *Validity* of knowledge: the extent to which a knowledge base is truly relevant to the subject of concern.

These parameters are tentative and conjectural, but they reflect a need to favour the development of knowledge that has inherent value. In the absence of a comparative scale, we may be allocating scarce resources to sub-optimal use. Which is worth more: investment in 100% knowledge about a disease that affects very few people, or investment in 50% knowledge about a health problem that affects nearly everyone? We cannot currently answer such questions because we lack consensus on the qualitative dimensions. Some attention to this issue might improve the future returns to expenditures on the production, mediation, and use of knowledge.

Finally, the near-term evolution in health care knowledge will almost certainly see visual elements added to the database. A good illustration of this expansion of the concept of knowledge is already available in radiology. Actual diagnostic images – not just radiologists' verbal interpretation – are increasingly stored in Picture Archiving and Communications Systems (PACS), and search engines are already being developed to retrieve them by image characteristics. For example, researchers can pursue knowledge of breast tumours by retrieving and studying all mammograms exhibiting specific morphological features. This image-based research process is much more powerful than the traditional review of radiologists' written reports which may have differences or errors in professional judgement.

This example is just the "tip of the iceberg". The emerging ability to store and analyse visual images relating to health care creates remarkable new possibilities for creators and managers of knowledge. We will be able to watch and study visual images as they change over time, just as we can already follow the movement of a storm via radar images. It is necessary to develop and apply visual skills for creating health knowledge in the 21st century, just as scientific literacy and numeracy were developed to understand the production, mediation, and use of health data in the 20th.

Key relationships and mediators in the creation of knowledge

Complexity is a key characteristic of the relationships among the various entities involved in production, mediation, and use of knowledge in the health sector. Indeed, analysis of the interplay between constituencies could be conducted from several perspectives, but a "7-p" transactional model – patients, providers, practitioners, payers, purchasers, pharma, pofessoriat – is adopted here to simplify the analysis. Some of the most important historical relationships are used, but this is by no means the only approach. The model initially reflects the legal parties to health care transactions: patients, providers, practitioners, and payers. (Consistent with a worthwhile distinction made by the Joint Commission for the Accreditation of Healthcare Organizations, or JCAHO, providers are defined as organisations, such as hospitals and medical groups, and practitioners are defined as professionals, such as physicians and nurses.) A fifth "p" is added for purchasers (*i.e.* the employers who buy employee health plans), a sixth "p" for pharma (*i.e.* the pharmaceutical industry), and a seventh for the professoriat, or academia. This "7-p" concept provides a useful framework for the remainder of the discussion.

The most significant area of interest for present purposes is probably clinical knowledge. It has mainly been produced in the United States predominantly by three constituencies: professors, pharma and the largest payer, the federal government (*e.g.* the National Institutes of Health). In the past, relations between these three parties have been collegial, but they are becoming more competitive. Some key forces behind the changes are the rising costs of product liability and litigation, political constraints on research brought about by social conservatives (the "religious right") and animal rights activists, accelerating mergers and acquisitions within pharma, near-term loss of patent protection for a large number of brand-name drugs, and disintegration of government health policy. Further, the traditional role of the university is threatened by academic inertia and by intrusion of for-profit corporations into adult education.

Analysis of the current dynamics suggests several other significant changes in the making. For example, venture capital has created an amazing number of start-up companies dedicated to pharmaceutical research in highly focused areas. These companies have tended to draw many top researchers away from academia, upsetting the historically congenial "town-gown" relationship in health care. The phenomenal expansion of the computer as a research tool also creates many opportunities to increase the knowledge base both in breadth and in depth (*e.g.* the Human Genome Project). All things considered, analysis of these forces suggests that the professoriat's loss is pharma's gain. Universities will probably decline in importance as contributors to knowledge, and the pharmaceutical industry will assume a more powerful role. Pharma's highly successful entry into the managed care business and the professoriat's simultaneous failure to develop managed care products are offered as additional evidence in support of this conclusion. The government's future involvement in health care knowledge seems relatively stable.

The situation is equally interesting in the overlapping realms of providers, practitioners, and private (*i.e.* non-government) payers. These three entities have produced extensive knowledge about paying for health care in the uniquely American way since the creation of Medicare and Medicaid in 1965. Now, the Health Insurance Portability and Accountability Act of 1996, also known as HIPAA or Kennedy-Kassebaum, is forcing all three constituencies to work together to "simplify" reimbursement. (However, the evolution of payment simplification immediately brings to mind the well-known French observation, "Plus ça change, plus c'est la même chose".) Their hard work may ultimately produce a new claims-processing system, but it is unlikely to produce new knowledge that will have any other impact on health care.

These constituencies are also preoccupied with the "Y2K" problem that will wreak havoc if computers are not reprogrammed to recognise the year 2000. Once that problem is solved, they will turn their attention to the even more daunting task of coping with the new universal patient identifier required by HIPPA. The complexities and uncertainties of payment reform will almost certainly keep these three groups so busy that they will not have time to produce desirable new knowledge (*e.g.* how to get appropriate services to uninsured populations, how to define medical necessity in order to fulfil the promise of managed care).

Growing division within the ranks of providers and practitioners will further divert attention from the research and development that would improve health care. One example is the simultaneous introduction in 1998 of Medicare+ which is designed to provide more managed care options under Title XVIII of the Social Security Act and implementation of provider-sponsored organisations (PSO) in order to provide competition for the traditional payers. A more subtle diversion will be the ongoing encroachment of qualified non-physician providers (*e.g.* advanced practice nurses, clinical pharmacists, therapists at masters' level) on the market that US physicians have monopolised since the early years of this century (see Bauer, 1998). The ensuing intra-group and inter-group confrontations will seriously strain the co-operation necessary to produce, mediate and use knowledge across professional boundaries. New data and information will undoubtedly be generated within the various groups, but, in light of the increasing competition, they will increasingly be treated as proprietary knowledge. In other words, the future is likely to see significant deterioration of the collegial relationships that supported widespread dissemination of knowledge in the past.

Purchasers have taken a lead in only one area related to knowledge, the attempt to define quality of care. Through the National Council for Quality Assurance (NCQA), many of the nation's largest corporate purchasers of health care have financed the development of the Health Care Employer Data Information

Set (HEDIS). HEDIS only provides a limited snapshot of health care services, but it does allow purchasers to compare competing health plans on approximately 30 criteria which include delivery of preventive services and compliance with selected care protocols. HEDIS has not significantly advanced the science of measuring the quality of health services, but it has established the practice of using "report cards" to compare different providers and practitioners. Comparative rating systems are definitely a new type of health care information in the United States, but the questions of whether they constitute good knowledge remains unanswered. The initial instruments that claim to measure quality appear to suffer from oversimplification.

The changing nature of knowledge-based relationships within and among the seven "p" is significant, but this does not imply that the production of important knowledge will decline. Indeed, even more resources are likely to be devoted to producing valuable knowledge, as the dramatic increases in investments in information technology over the past two to three years suggest. The key difference between the past and future is that owners of the new knowledge will be able to profit directly from it in competitive markets. New knowledge will be more proprietary and less public as a result of the recent shift in government policy from ensuring collaboration to promoting competition.

The "winners" in the new knowledge marketplace are likely to be the corporations within each sector. No single "p" group is destined to dominate the others, but early evidence suggests that pharma is positioning itself to be the leading sector. Providers of speciality services under managed care plans are also making investments that arguably enhance their prospects for success as a result of superior, proprietary knowledge. This might not happen if the largest payer, government, showed signs of returning to more collaborative policies. For better or worse, it does not. Promoting competition and punishing fraud and abuse seem to be the hallmarks of government policy for the foreseeable future. Consequently, privatisation will probably be a key characteristic of American health care knowledge in the near term.

Special interests and health care knowledge

Each of the seven "p" groups is a special interest, working diligently to protect its position in the US health sector. However, a generic assessment of each group's current actions suggests major differences in the priority assigned to knowledge as a strategic goal. While there are exceptions, group-specific summaries are presented here as a basis for further discussion.

Practitioners are engaged in an intense battle for market share. Until recently the unchallenged leaders because all other health professionals operated under their authority, physicians are becoming a considerably less cohesive group than they have been for nearly a century. Traditionalists are engaged in defensive action to protect the "good old days" of solo, fee-for-service practice. However, a growing number of recently trained doctors are becoming comfortable with managed care, particularly the notion of working for someone else and sharing authority with corporate managers. Producing new knowledge does not seem to be a high priority for either group. A relatively small group of doctors from all backgrounds are starting to think and act like entrepreneurs who wish to redefine clinical practice and are those likely to develop new knowledge on how to manage health care resources (see Weed, 1997). These progressive "healer dealers" have no time for the American Medical Association because they are busy meeting with venture capitalists.

Hospitals, health systems, and other organisational providers are currently so preoccupied with mergers/acquisitions and internal reorganisation that they have very little time to devote to knowledge that would improve the services they actually deliver to patients. Providers' remaining energy is absorbed in complying with the constantly changing and ever-expanding regulations of the Health Care Financing Administration. The only organisation that forced providers to think differently about their future, Columbia/HCA, virtually disintegrated as a market power in late 1997. Providers are unlikely to be leaders in the development of new knowledge paradigms in the coming years, but many will have the capital and infrastructure to apply knowledge generated elsewhere.

Payers are expanding the quantity of health care data at a remarkable rate, but there is no clear evidence of a co-ordinated strategy to turn the data into beneficial knowledge. Indeed, the notion of information entropy comes to mind when one ponders the sheer volume of data generated by the management of patient accounts. The best hope for learning something useful from payers' numbers may come from the new tool of "data mining", as more providers and practitioners adopt electronic medical records. Speciality companies are beginning to demonstrate the value of looking simultaneously at payers' databases and medical records in new ways, and significant progress may be made. Ironically, a branch of the federal government (Agency for Health Care Policy and Research, AHCPR), which was a pioneer in creating outcome-based knowledge from payers' data, was ultimately "punished" for encroaching on private markets.

The professoriat seems to be in a general state of turmoil. With a few notable exceptions, universities have not been successful in redefining their roles in response to changing circumstances. Many R&D activities are still being conducted in universities, and overall resources for academic R&D seem to be increasing. However, this growth seems to be accompanied by a shift in motivation from the academic (*i.e.* doing pure research to serve society) to the entrepreneurial (*i.e.* doing applied research for specific sponsors). Universities have worked hard over the past decade to diversify the sources of their research funding and are likely to continue to be heavily involved in producing health care knowledge. Whether they will be long-term leaders is another question. Many university-based research laboratories are heavily dependent on private funding, and top researchers are increasingly willing to leave academia for private industry when they are on the verge of making major discoveries.

In addition to facing "real world" economic temptation, professors in the United States are struggling to preserve their traditional role as editors of academic journals that disseminate health care knowledge. This task has become rather difficult, given changes in the publishing business. Paper, printing, and distribution costs have all risen dramatically over the past few years, yet the number of journals has proliferated with the growth of special interests. Journals also lost advertising revenue as drug companies began promoting their products directly to consumers in other media, and library subscriptions have declined. The outlook for traditional health care journals is bleak, but the impending demise of hard-copy distribution does not necessarily doom the professoriat's traditional role of managing knowledge distribution. The key to continued success is to manage the shift from print to electronic transmission. If professors do not promptly assume leadership in this area, there are many other "editors" waiting to take their place. Providing adequate editorial control over the quality of on-line information will be a real challenge in the world of electronic publishing. Gresham's Law stands as a serious reminder of the challenge. Bad knowledge will drive out good knowledge without proper leadership and safeguards.

Pharma, as already noted, is probably positioned to become a leader in producing knowledge that will change health care in the greatest number of ways. Pharmaceutical companies are already the obvious leader in applications of biological science to diagnostics and therapeutics. They are also extensively involved in development of knowledge that will influence virtually all aspects of health care delivery. Pharmacy benefit management companies are only the most visible examples of a growing number of pharma-linked ventures that are quietly developing databases to achieve competitive advantage in virtually every sector of the health care market. Of the seven "p" groups, pharma also best fits the condition of Sutton's Law. It's where the money is.

The patient is last, but definitely not least, in this analysis. Patients are not at all likely to become developers of health care knowledge in the United States, but for a variety of reasons, they may soon become major forces in its mediation and use. For example, consumer protection has recently emerged as a major force – in some instances, almost the only force – in current efforts at health care reform. Consumer choice is also rising fast in areas as diverse as the "death with dignity" and patient self-determination movements. Furthermore, self-care is now recognised as a major opportunity for market growth. But the most significant force may be the political and economic power of the "baby boomers" who are just entering their prime years. This is the generation that pushed out two US presidents, ended a controversial war, made a lot of money, and otherwise became accustomed to believing that people ought to listen to it. Their potential role in reshaping the future of health care knowledge must not be underestimated.

Other key determinants of innovation

This perspective on the state of health care knowledge in the United States at the end of the 20th century is reinforced by two other significant forces: *i)* the rapid development of telemedicine as an enabling technology; and *ii*) open acceptance of profit as a primary motive for economic activity in all aspects of health care delivery. The simultaneous convergence of these forces suggests the possibility of explosive innovation in health care knowledge.

Telemedicine is suddenly being recognised as a truly revolutionary force. Resulting from the merger of cutting-edge technologies in telecommunications and computers, it is redefining almost every health care relationship and transaction. Telemedicine potentially gives new power to all the "p" groups, especially patients. It liberates medicine from the constraints of time and place that have prevailed since the age of Hippocrates. It also requires new payment mechanisms, licensing laws, liability protection, ethical concepts, ownership of intellectual property, and virtually every other aspect of health care delivery. Telemedicine must not be underestimated as a key determinant of innovation in the production, mediation, and use of health care knowledge in the new millennium.

The other key determinant of future innovation is the logical result of the corporatisation of American medicine (see Paul Starr's prize-winning book, 1982). It is the acceptance of the profit motive as a legitimate justification for economic activity in the medical industry. The history of the creation, mediation, and use of health care information is largely explained by the development of a long-standing and comfortable relationship between payers and professoriat, but privatisation of reform has been accompanied by a shift from government subsidy to private profit as the predominant factor. The government is neither out of business nor out of the market – indeed, its contributions to knowledge are large and constant – but the relative role of entrepreneurial activity has increased substantially and can be expected to increase further. The American political climate now favours private sector activity motivated by profit and will probably continue in this vein for several years to come. Therefore, those who want to understand the evolution of health care knowledge in the United States for the foreseeable future are well-advised to base their thinking on economic models that explain rational economic behaviour as a function of the profit motive.

Knowing the least-cost combination of resources to produce desired outputs is probably the key to financial success for any economic unit that wants to survive and thrive in the US health sector over the next few years. Knowledge of the most cost-effective way to provide health services will be the key to success, and it will most likely be developed first by economic units (*e.g.* pharma, speciality providers) that were not closely involved in the traditional knowledge relationships before privatisation. Patients will be the new mediators in this redefined marketplace. This revolutionary vision of the future is uniquely American at the outset, but it may ultimately have a major impact on health systems in other countries that have managed their health resources to meet social imperatives. Why? Because it may ultimately yield better results than any of the alternatives.

Conclusion

The history of the production, mediation, and use of knowledge in the US health sector reveals many strong and well-organised relationships. However, the underlying dynamics of these relationships are changing dramatically, and the future may be very different from its past. Privatisation of health reform, the consumer movement, rapid adoption of new information technologies, and the rise of entrepreneurial activity are among the many powerful forces that are creating new types of knowledge and redefining relationships among the patients, providers, practitioners, payers, purchasers, pharmaceutical companies, and professors (universities) involved in health care knowledge. Patients, progressive practitioners, and pharma seem to be positioning themselves for leadership roles as a result of shifts in government policy. Many providers, practitioners, and professors may experience erosion of their historical positions in the knowledge business. However, the most significant conclusion of this analysis is that the United States is experiencing a shift in the basic paradigm of health care knowledge, with special efforts being devoted to understanding the cost-effective allocation of health resources and harnessing the power of the Internet to serve new markets of empowered consumers. Nothing is certain in such exciting times, and the future may produce some surprises.

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INFORMATION, COMPUTERISATION AND MEDICAL PRACTICE IN FRANCE AT THE END OF THE 20th CENTURY

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Introduction

France has launched an ambitious programme of systematic computerisation of doctors' offices, creation of an Intranet network for health professionals, and distribution of "smart cards" to all those covered by national health insurance (Sesame Vitale I) and ultimately to all French people (Sesame Vitale II). Health professionals will also receive a specific type of card. The goal of this operation is, in particular, to transmit health insurance claims to the national health insurance bureaux.

The present writer was requested, in February 1997, by the office of M. Jacques Barrot, the then Minister of Labour and Social Affairs, to evaluate these computerisation projects and to consult with relevant experts as necessary. In November 1997, a report entitled "The microprocessor and the stethoscope: information and computerisation in the health sector. Is failure in this area unavoidable?" was presented to Mrs Martine Aubry, Minister of Labour and Social Affairs.

This article only gives an analysis of the reasons why medicine is no longer possible without computers, networks and software.

Why the practice of medicine is no longer possible without computerisation

A few brief remarks will make this clear.

The domain of medical knowledge has expanded to such a degree that a human mind can no longer retain it all.

There are now some 20 000 medical journals in the world.

A professor of medicine spends on average one day a week to remain abreast of studies in his/her field of interest as well as for his/her research. What can a generalist physician do? How much time can he/she devote to "keeping up"?

In France, there are some 7 000 prescription drugs based on some 3 500 active ingredients. A physician has the right to prescribe them all. Can he/she be familiar with all of them? He/she must also be aware of some 300 medical references, some 800 biological tests, over 1 000 imagery tests, and more than 1 500 surgical interventions.

If he/she prescribes six drugs, he/she must also be aware of some 720 potential sources of interaction. The figure reaches 3 328 800 if ten drugs are prescribed.

In addition to the therapeutic value of each molecule, the physician should also know their price and potential effect on specific population groups (diabetics, the obese, children, the elderly, etc.).

The growth in knowledge has necessarily led to specialisation, which too often in France has meant "balkanisation" and lack of co-ordination, especially in hospitals but also in private practice.

As knowledge is shared, responsibility and decisions about treatment should be shared as well, as has long been the case in cancer centres; however, this is the exception rather than the rule.

Access to knowledge through continuing training, which is now mandatory, cannot be the only response to the problems evoked here. Medical schools today recognise 56 different specialisations and in fact there are at least a hundred. If each generalist spent only half a day a year to learn about trends in each of these fields, this would mean between 28 and 50 days of retraining a year. This is unthinkable. What is needed today is to know how to gain access to knowledge. One needs to be able to sift the body of information available.

Computerised information systems may give an answer to the question of access to knowledge. One can imagine:

– Data banks (involving text and images as well as figures) which act as medicine's memory to be used for research (clinical, pharmacological, epidemiological, etc.).

– Knowledge banks (bibliographies, sites for exchanges among professionals, etc.) which make it possible to have access at any moment to the state of the art and can help in making a medical decision (diagnosis or treatment).

– Software to help with diagnosis and prescribing which does not replace the physician but act to extend their knowledge, just as the backhoe effectively extends the arm of the construction worker.

Medicine will nonetheless remain an art, like architecture, despite its many uses of computer applications.

This "art" has evolved greatly in the course of the past half-century: in their work, physicians use technical devices (medical imaging, for example) and chemical, immunological or genetic principles which are close to exact sciences. As it is used by and for human beings, there is risk in the use of reproducible and scientific methods. In this sense, which is not common sense, medicine would be a human science or rather a practical art which finds it legitimacy in scientific knowledge.

These data banks can be readily accessed through a network (Internet or intranet) if the user has at his/her disposal a workstation, software, passwords that give access to these networks and their different sites.

The system is flexible, adaptable in time and space, and can be customised: each physical can, when he/she wishes, consult one of the banks or receive specific information on the fields which he/she has chosen in advance. Access need not be limited to physicians alone, but can also be made available to health professionals and the public, and the latter could adapt behaviour to help prevent the onset of illness.[1]

Of course, these data banks have to be organised, updated continuously and meet users' expectations by allowing them to ask questions and to engage in discussions among themselves. Researchers throughout the world who use the Web have had this modern forum available to them for several years. For the use envisaged here, it is indispensable that each source contain the following information: author, date of last update and mode of accreditation, so that it is always possible to evaluate the quality of the information consulted.

If the market can be expected to offer software diagnostic and prescription aids, it is up to the public authorities to invest so that the elements of this "knowledge network" can be created. The amounts required, while substantial, are not excessive.

The knowledge network can also make it possible to consult experts located elsewhere and to transmit images and other elements of a patient's file to a colleague to obtain an opinion, a practice currently known as "telemedicine".

Technically possible for more than a decade, telemedicine has essentially only been developed between university centres. This is because it raises three types of question which, being unresolved (but are they even raised?) slow its dissemination to private practice. They concern the sharing of responsibility between the person who enters the information and the person who interprets it, the sharing of fees and thus of income, and finally the sharing of patient confidentiality. When will the public authorities and the medical insurance bodies address these questions?

Finally, it is worth recalling a fact that is plain to all: electronic mail is quicker and cheaper than the mail service or fax. It is therefore an ideal medium for transmitting information about a patient: letters from hospitals to the attending physician, results of medical tests, specialist opinions, follow-up of the assignment of a private nurse, etc. However, there is the question of the confidentiality of e-mail, unless it goes through a secure site. However, we should face facts. Today, fax, telephone, audio and video documents all work in a haphazard way. Faxes do not always reach the right person. The excessive rigour or modesty that affect the implementation of the health network contrasts with current practices in other areas. Coherent action is needed in all these areas.

Why financing bodies: Do health insurance bodies need computerisation?

The first reason is an old one. Computers are totally compliant, incredibly quick to carry out certain types of repetitive tasks, lacking in initiative and intolerant of ambiguity, and they have increased productivity in claims departments by relieving the staff of certain tasks with such characteristics.

Until recently, claims offices were no more than immense machines for reimbursing medical expenses, and computerisation has definitely helped them to do this work. A few simple comparisons between offices show that important productivity gains would still be obtained if all were organised along the lines of the most productive. If employment is to be maintained, it follows that a share of the personnel would have to be oriented towards new activities.

If the health insurance system ceases being simply a blind, if rapid, reimbursement mechanism and begins to act instead as an attentive and informed payer, both the nature of the information it treats and its computer system and internal organisation will change as well.

In the name of those insured that the health insurance system is supposed to represent, it should only reimburse what is medically justified and not, as it does today, reimburse physicians' prescriptions on no other basis than the correspondence of the prescribed drug to an agreed nomenclature.

This is not yet (at the end of the 20th century in France) a simple case of financial means, as the public considers that health spending is a priority and should be financed where necessary.

But what is a "necessary" expenditure? The notion of necessity comes from the encounter between a patient's situation and the state of technical and medical services that make it possible, at a given point in time, to cure him/her or relieve his/her suffering. What allows us to say, from this point of view, that the French system is not optimal and that it is therefore necessary to implement risk management tools?

Among the thousands of examples that could be cited, it is worth noting the following:

- French people use 20 medicines per person per year, whereas Germans use 14 and the English 8.
- France is the only western country to prescribe in private medical practice certain types of drugs that are not or rarely prescribed in hospital, as their therapeutic value is very questionable.
- Certain hospitals treat certain diseases at costs that are three times below those in others, although it has not been shown that the quality of care justifies the difference in costs.
- Depending on where the consultation takes place, the charge for the same category of specialist may differ by a factor of three, although there is no medical justification for the difference.
- The health insurance body (CNAM-TS) has shown that the frequency of certain surgical interventions also varies from region to region to a degree that cannot be explained by demography or epidemiology (operation for cataracts, appendectomy, etc.).
- More that a quarter of emergency admissions to hospital appear to be due to illnesses brought on by medical treatment and particularly by dangerous side effects of drugs. Clearly, doctors do not always prescribe appropriately. Such problems appear to lead to three times as many deaths as traffic accidents. (This figure is an extrapolation to French hospitalisation figures of a study done by a Harvard team on medical accidents in the state of New York in 1983. The estimate is probably low; see Wecler *et al.*, 1993.)

– According to the limited studies available, side effects due to hospital treatment appear to be very high (over 15%), in certain departments of certain institutions.

– The *Mutualité Sociale Agricole* (Agricultural Health Assurance) has also demonstrated that the necessary precautions to take proper care of a patient are not always taken and that, for example, there is not always a record of eye examinations in the treatment of diabetics.

There therefore appears to be both over- and under-consumption of medicine.

There is a two-pronged reason for this: the complexity of medicine, on the one hand, and the absence of control, on the other, in a system with collective financing. As the line between prescription (including prescription of a further visit) and income is obvious, this link itself justifies controlling medical appropriateness and number and price of the prescribed medical treatment. Whether insurance is private, as in the United States, or socialised, as in France, the basic justification for controlling medical expenses is everywhere the same. This point, moreover, not only concerns France. In the United States, George Anders (1997) has written that "one can simply no longer have confidence in doctors and hospitals that lack controls". The latest North American figures seem to indicate that there is no difference in the quality and effectiveness of care obtained by Americans who pay their doctor by the consultation and those who belong to an HMO, whose physicians are, in most cases, salaried.

The first group pays 22% more (Rothman, 1997) than second (around FRF 150 billion as an equivalent percentage of total health costs in France), but, in the second group, patients are more dissatisfied as they have been unable to choose their physician themselves.

Without entering into a discussion about whether or not one should be free to choose one's physician, it is clear that the health insurance system must, in order to build a means of control, meet a certain number of technical conditions. It must:

– Choose points of reference that it cannot produce on its own for reasons of conflict of interest.

– Collect data that allows it to compare, at least in certain cases, the treatment actually applied (price and amount) and the treatment that serves as a point of reference.

– Be able to act to modify behaviour that is deemed inappropriate, in other words be able to offer incentives and apply sanctions (lack of reimbursement, removal from the National Health list).

What is needed is to design a potentially exhaustive means of control in real time, rather than a statistical control. Local health authorities need to have rapidly the tools that will allow them to play the role they are allotted by law. If there are no national points of reference, these will be locally determined and heterogeneous and will raise questions of equity.

For this process to begin, it is necessary to:

– Be able to assign a code[2] to illnesses or the reasons that lead a patient to consult a physician (a classification of the type made by R. N. Braun is necessary for private medical practice).

– Be able to assign a code to the medical treatment.

– Be able to assign a code to prescriptions, including drugs.

– Transmit these data (illnesses, medical treatment, prescriptions).

– Process them and react rapidly, sometimes in real time, to ask the reasons for a prescription, continuation of a hospital stay or the price of a prosthesis.

This instrument should be a secondary product of medical work and not heavy and ineffective bureaucratic red tape.

Finally, physicians should be able to contest, in ways to be defined, any decision that would appear inappropriate for their patient. The system should be "reasonable" and not bureaucratic and look to the desired goal and the underlying philosophy, and thus be founded more on a delegation of responsibility than on the production of laws that will one day necessarily become inappropriate.

Can computerisation contribute to meeting the expectations of the French public and of health professionals with respect to the organisation of the health care system?

Citizen, patient, beneficiary

Citizens want the system that they pay for to be well managed. Through parliament, an accounting should be made to citizens every year.

The persons ensured, for their part, want the highest level of financial coverage and rapid reimbursement. The waiting period today is less than five days on average but is still too irregular.

Finally, patient-beneficiaries would like:

– Minimal bureaucracy.

– Flexibility.

– Access to their personal information and general information (databases).

– Reasonable use of medical data.

– To be able to benefit from knowledge about the latest treatments for his/her problem.

This argues in favour of:

– An access card for each beneficiary.

– A simple and efficient procedure if the card is lost or forgotten.

– Possibility of access to one's medical history.[3] This would be a choice on the patient's part and not an obligation, and would therefore require the organisation of an archiving system for medical records. Many French people are ready to pay for this service, for which a medical card will never be adequate, as it will always remain partial, if indeed it ever exists. The medical record would always be accessible; it would not be lost, and the data would be trustworthy, exhaustive and verifiable.

– An effective legal procedure that would make it possible to prosecute any improper use of an individual's information.[4]

– The possibility of access to health education locations and to specific medical data in the case of serious illness.

The physician

For the physician, computerisation is not a goal.

We have seen that networks give access to data banks. However, it is necessary:

– That they exist.

– That they should be of easy access.

– That their contents should be in French.

– That consulting them should not be too expensive.

– That their contents are trustworthy.

As a pedagogical tool, computerisation allows for initial training, continuing training, regular attention to themes of particular interest, following trends in certain areas, etc. Access to bibliography allows the physician to reassure him/herself as to the appropriate steps to follow, and it is an important safeguard and a powerful and flexible tool: at any hour of the day or night, he/she has access to the great libraries of the world. Today, all knowledge is available, but the problem is to know what is needed and its price. Finally, computerisation can help every physician to mobilise his/her experience optimally by using self-evaluation mechanisms.

How will the computerisation of physicians' offices modify medical practice?

In his/her daily practice, the physician is faced with the problem of treating a great quantity of information so as to:

– Orient and then establish a diagnosis.

– Understand the patient's illness.

– Envisage an appropriate treatment. Where necessary, ensure that this treatment does not conflict with others already being carried out. This is important for patients with chronic illnesses, which are ever more prevalent.

Clearly, this requires bringing various types of information together and finding the relations between them, something that a computer, by its very nature, can do.

For the physician, computerisation will therefore be a formidable aid to decision making. However, he/she only has two or three minutes per consultation at most to enter, consult and produce information.

In what way is this tool likely to modify medical practices?

The broad lines of this modification are described below.

Standardisation of medical practices

It is legitimate to suppose that the possibility for the physician to refer to best practice tools or to compare his/her options to reference points will encourage him/her to exercise his/her profession differently. The large range of practices that exist today are likely to be narrowed, and there will soon be greater standardisation than there is today.

This is a tool that will make possible the diffusion and easy use of the tables contained in reference works and the easier this is (and business people will know how to accomplish this), the quicker the goal will be reached (contrasting medical points of view, drug incompatibility, etc.).

Better knowledge of one's own practices/an end to isolation

Computerisation and ease of access to databases will show the physician (who is, again, often alone when a decision must be taken) that others have asked themselves the same question, have searched for the best solution and have sometimes found it.

This will tend to limit the "halo" effect that a medical profession unconsciously creates [realise] with respect to an illness or a patient.

Moreover, the use of data banks can allow the physician to examine his/her own practices, with respect to costs or effectiveness.

Relations/exchanges among medical practitioners

Exchanges of information among medical professionals will be facilitated and will therefore multiply in both volume and quality. It will no longer be necessary to give up information in order to pass it on to a colleague.

All health professionals who are involved with a patient will be able to communicate and one can expect to see better co-ordination of the care given. At the same time, the physician will have closer relations with colleagues and teamwork will be greatly encouraged.

Physician/patient relations

It has been said that the presence of a computer in a physician's office and the fact that the physician uses this tool and types instead of looking at the patient who is describing his complaints could modify the relations between physician and patient and perturb the well-known "doctor-patient relationship". In point of fact, it appears that patients, already accustomed to this tool in almost all areas of life, are not perturbed by this new application and even find it quite natural. It is not the tool that will make the relation suffer. However, it is possible that the time spent in front of the screen as the information is being downloaded may trouble the physician. Industrialists will have to be vigilant in this respect.

Computerisation will also cause the public to make more demands on the physician. This is because, aside from physicians *à exercice particulier*, all will be able to refer to acquired knowledge and to base their treatment on reproducible effects.

This is not very new, because prior to any individual decision on the part of the physician, tests have always been carried out (and are required more and more). The pharmaceutical industry was undoubtedly first in this area and the rise in various pressure groups (for blood, materials, etc.) points the way.

If the physician considered this as natural, he/she would certainly have had to feel that it would also be his/her obligation one day as well. That day has come, because the tool makes it possible.

However, decision making, even when backed up, will always be a reflection of the physician's knowledge, insofar as, as the decision-making process advances, the choice will be made on the basis of what the physician has learned in the past.

But, let us imagine that medical practice evolves to the point where one day it becomes exclusively based on proof and controlled tests. The quantity of information necessary would be so great as to be unusable. This nightmare has little chance of being the precursor of a future reality. It is true, however, that the demand for results will become stronger and stronger. If the physician's responsibility is not to be held excessively responsible, it is necessary to take a new look at the ethical and legal aspects of medical responsibility.

The diffusion to the public at large of medical information requires protection against a Manichean use of certain data, hasty judgements or the manipulation of public opinion on sensitive but complex subjects, especially when the media amplify the accidents that occur. Zero risk does not exist, with all the knowledge in the world, in any human activity. The question is a burning one at the present time.

Finally, there is the question of the trustworthiness of sources. How is it possible not to fear that in the formulation of articles or press releases, their interpretation might serve certain lobbies? How is it possible not to take account of the sometimes contradictory nature of articles that appear under prestigious names on studies all of which have been "scientifically" carried out?

It is a question in the first case of work founded on economic objectives, in the second on scientific objectives, but who will verify in the future the quality of the information? Not the state but health professionals themselves if they accept this as their mission.

Physician therefore need:

- Computers (and not electronic boxes for transmitting health insurance claims).
- An effective tool which is difficult to counterfeit and which will be their access key and their electronic signature: the health professional's card.
- The creation of data banks and sites specifically dedicated to them, on the condition that the information is validated, dated and the signer known.
- Simple and rapid procedures that make it possible to communicate with partners: health insurance, colleagues, paramedical professions, patients.
- Industrials who provide, maintain, and explain how these tools and the associated software work (the role of training is not negligible in a country where the use of the keyboard is not part of the general culture). It should be underscored that maintenance and assistance cost two and a half times the purchase price and that the purchaser is initially more sensitive to the quality of the product that the quality of the service. Professional associations should guide purchaser on these issues.
- Trustworthy, frequent and global reports on the information they transmit to the health insurance body to serve as a means of self-evaluation.

– Understanding of the constraints that they impose on themselves when they choose not become computerised. An absolute requirement to do so and/or excessive penalties are, clearly, a sign of weakness on the part of the public authorities.

Physicians thus need a body of computer services which do not yet exist and remain to be created, as was once the case for the telephone. But which is the chicken, and which is the egg? These services will not exist as long as the computerised medical network has not taken shape. For their part, physicians can legitimately question the value of computerisation if it is no more than a source of paperless health claims. The role of the state is to allow the actors to go beyond this apparent paradox: it can only be an incentive that lies between constraint and civic-mindedness, not an obligation that would carry sanctions.

The consequence of this analysis is to call into question the position of the National Health (CNAM) and software publishers who say, "first the electronic health claim, the rest will follow". When it is time to add to this mechanism, it will become apparent that what has been designed will have to be modified. The more ambitious decision was made by the Danes, whose MEDCOM covers all of the needs described above.

Pharmacists

Like physicians, they can have data banks and dedicated software at their disposal. This profession, already highly computerised, as physicians are not, will have to adapt to the future system and standards. Who will finance this adaptation?

Other health professionals

The reasoning is the same as for physicians. The question for them is to know under what conditions they can have access to the personal medical information they require to do their work. Who gives authorisation? For what length of time? It seems that these very practical topics have yet to be addressed. Some physicians would like to see the creation of a true meeting ground where knowledge can be exchanged and obtained and where the other health professionals are partners.

The hospital or the clinic are an element of the information network insofar as the patient and National Health are concerned, but they are also a location in which a specific, autonomous network is created.

What has been said for each private physician (with the exception of relations with National Health, which is the responsibility of the institution and not the care giver) also applies to the establishment which provides the care.

In addition to their administrative functions, which have been computerised for more than 20 years, an ideal hospital system should aid in the organisation of work, on the one hand, and the sharing of medical information, on the other. Here again, this ideal is rarely the case.

From principles to reality

The current situation is far from idyllic.

First, there are technical reasons:

– All doctors do not use computers.

– The technical adaptation of existing software, including for pharmacists, does not seem to have been carried out and pharmacists refuse, at present, the Sesame Vitale I card.

– The rate of electronic transfers is low (about 60%).

– The services potentially available on the network are few in number.

– The issue of advertising has not been resolved.

– The knowledge network is not organised.

However, that is not the essential reason. The National Health body does not possess an organisation that allows it to interpret the data, as health insurance companies or American HMOs are able to do:

– The existing references point are not very effective and their applicability is limited.

– There are no guidelines for frequent and/or expensive diseases.

– There is no coding system, except for illnesses for which all expenses are covered; and in this case, the diagnosis is known to the Social Security offices but is not used.

Unless this very ambitious and interesting project evolves differently, even if it works in a technical sense, it will not work in an economic sense and the French health care system will continue to be what it is today: an immense apparatus for reimbursing health care costs.

However, there will still be a health/social services network and a medical profession that is familiar with this tool and the power of the Internet. The experience will not be totally negative, even if it is likely to reach goals that are different from those set at the outset.

NOTES

1. It should be recalled that today time is wasted when using the Internet. In the future, specialised servers will be needed, between users and the www, and training and help for users will have to be provided.
2. This does not necessarily require a numbering system but does require a contractual interpretation of an unambiguous piece of information.
3. At present, the law only allows access via a physician designated by the patient.
4. This position diverges significantly from the traditional French position which has privileged: destruction of files, limitation on use and other actions by the CNIL (Commission Nationale Informatique et Libertés) thereby creating an obstacle to any control policy and sharing of patient coverage.

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HIGHER EDUCATION RESEARCH IN EUROPE

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Introduction

There is a long-standing literature about the relationship between research, policy and practice (*e.g.* Weiss, 1980, Husén and Kogan, 1984; Anderson and Biddle, 1991; Nisbet and Broadfoot, 1980; OECD, 1995), although only a small proportion (*e.g.* Sadlak and Altbach, 1997) is directed to higher education.*

The research agenda shares many common features with other phases of education and areas of social policy: the extent to which research competently covers the area from the perspective of policy makers and practitioners, whether the nature of a policy and practice zone gives rise to particular forms of knowledge, the extent to which there is transmission of knowledge, and what obstacles exist to transfer.

It is tempting to look for simple correspondences between the problem area, the knowledge generated, and the forms of transmission and implementation. This paper seeks such correspondences but also questions related assumptions. One is that it is less the nature of the knowledge generated than the social and institutional characteristics of main players that constitute the primary factors in transmission and transfer. Second is the assumption that all principal kinds of knowledge – positivistic, theoretical-critical and applied/action research – can illuminate policy and practice and that, while there might be an inherent conflict among them, they might ideally create a virtuous and reinforcing cycle in which statements about the overall characteristics of systems could lead to a critique of existing policies and practices and both test and extend the scope of existing theories. Third, it is assumed that while these three kinds of knowledge may seem to relate to linear, illuminating and collaborative forms of transmission and use, there are no absolutely contingent relationships between, for example, positivistic knowledge and linear forms of transmission. Finally, there are propensities for certain kinds of knowledge to be particularly useful at particular levels of systems, but such associations should not be regarded as iron-clad.

In the uncertain state of knowledge about the use of higher education, it is important to look at potential patterns of connection and not to focus too much on empirical evidence of existing connections. In this paper, the knowledge characteristics of higher education research (HER) and the modes of its production, transmission and use by practitioners and systems are considered under the following headings:

- The status of higher education research.
- Higher/tertiary education's knowledge needs are different from those of compulsory education.
- The impact of policies on HER.
- Knowledge styles.
- Knowledge requirements at different levels.
- Conditions affecting transmission and use.
- Summary and policies for HER.

* This paper depends to some extent on telephone discussions with knowledgeable informants in France (Christine Musselin), Germany (Ulrich Teichler), the Netherlands (Peter Maassen), Norway (Per-Olof Aamodt) and Sweden (Marianne Bauer), as well as inputs from Mary Henkel (England).

The status of higher education research

Higher education (HE) is a principal producer and disseminator of knowledge, but little attention is given to knowledge about HE itself by academics and institutional policy makers (Teichler, 1996). Yet higher education studies display all of the characteristics of domain-based knowledge (Trist, 1972); that is, unlike disciplinary knowledge, they start with problems of practice or policy and use disciplinary knowledge to solve them. Their reference groups are practitioners and academics.

The institutional base for higher education research is patchy. In Europe, smaller and medium-sized countries – Sweden, Norway, the Netherlands, Finland – have led the way in funding and making use of systematic research. Some national systems have been generous in according funds and legitimacy to basic and critical research; Sweden is the notable example (Trow, 1991). Norway funds generously but expects good policy return. Other countries, particularly those operating under the heroic ministerial model, fund on limited terms for limited purposes, and good work is performed mainly by individual scholars or small groups working on funds secured on a project-by-project basis. Of the larger countries, only Germany has a well-founded major centre.

The credence given to educational research differs among countries (OECD, 1995), and it is difficult to find relationships between educational research and HE policy making. There are, however, exceptions which may yield information about how higher education research might affect higher education policy and practice.

One example involves research of a largely positivistic intention but used for critical interrogation of public policy. In many countries, studies of social differentiation and access have fed the policy debate. An outstanding feature of higher education policy since the 1950s has been its "massification". In the United Kingdom, expansion was demand-driven to some extent owing to the lack of places for competent school leavers. At least two main streams of research legitimised and perhaps in some cases directly justified expansion. The influential Robbins report on higher education (1963) used research demonstrating the link between economic and educational development and establishing the extent to which an elite system excluded able young people from lower socio-economic groups. Expansion in the United Kingdom was already under way and research was attendant on policy and not its driver. Germany, where anxiety grew in the latter 1970s about over-production of graduates, offers a clear example of linear and rational research. Government-commissioned comparative research undertaken by the Kassel Centre allayed some of that anxiety.

In another example, critical and theoretical research changed paradigms or "assumptive worlds" and then lent force, albeit indirectly, to the democratisation of higher education. The critique of knowledge production and power relationships advanced in the sociology of knowledge – a field in which interpretative scholarship rather than empirical or analytic research has been most evident – must have done much to reduce the status of the university as a protected and specialist institution and the authority of the professoriat. This made it easier to give a stronger place in the governance of the university to junior staff, students and external client groups.

In France, the Faure reforms of 1968 aimed to endow universities with autonomy (Musselin, forthcoming). They were less the product of new research than of research-based expertise in government-appointed committees and two conferences held in Caen in 1956 and 1960. In these reforms, scholarly critiques of existing structures played a part. In Hungary (Setényi, 1997), research findings affected the policy discussion, if not the outcome, for student fees; the official committee depended upon academic research findings to move away from old public sector deficit assumptions and towards findings, from both Hungary and the West, that free education may block expansion and that a distinction must be made between public and private benefits.

At another level, higher education's curriculum and modes of transmission have been the subject of much reflective and normative thinking, partly under the pressure of reforms. Here, one would expect a difference between the use of research by policy makers and by academics. Government initiatives such as the Enterprise Initiative in the United Kingdom (Jones, 1996) have been based on ministerial instinct rather than on disciplined enquiry, which has generally shown that in some countries (Boys *et al.*, 1988;

de Weert, 1998) the academy was already changing on its own. At the practitioner level, research is likely to encounter the intellectual self-confidence of academics and their autonomy in matters of curriculum. In spite of a fairly strong policy discussion and pressures often triggered by the installation of quality assurance for teaching, research indicates that UK academics are little interested in such research (Gibbs, 1995; Henkel and Kogan, 1996).

In France and the United Kingdom, it cannot be said that HER, scholarship and policy analysis have generally had a clear impact on either policy or practice. In the latter, the recent D*earing* R*eport* (1997) on higher education avoided reference to either UK or international research on its main themes. Instead, it relied mainly upon official reports on the nature of higher education in other countries and on enquiries made by consultancies and policy institutes. One cannot assume that research in these countries is of poorer quality or does not fit the policy agenda. Other explanations involving institutional characteristics must be considered.

Why higher education is different

Before considering the knowledge characteristics of higher education, the extent to which higher education differs from other phases of education, and other fields of social intervention such as health, should be noted. All public sector activities concerned with personal welfare and development share problems which can be conceptualised in similar ways, such as the relationships between individual professionals and the employers; the nature of institutions, which analyse needs, create policies and determine priorities; and issues of access to and delivery of services. They differ, however, in their connection with their knowledge bases and the technologies they use and, therefore, with respect to social and power structures. Health shares many features with other welfare services but has a stronger scientific and technological component which tends to affect not only clinical knowledge, where both skills (Hargreaves, 1997) and scientific-based knowledge mingle, but also the approach to research on systems where, for example, evaluative constructs tend to emphasise discernible and measurable outcomes (Kogan, 1997).

Within educational research there are major divisions. While higher education shares some of the knowledge base needed for compulsory education, it has its own distinctive requirements. In particular, it is a field where conflicts over normative issues – what higher education is for and who controls it – are never far beneath the surface. Indeed, much writing on higher education has been more normative than empirical. The main differences from school level education are:

– Compulsory education largely meets social expectations which may be expressed through law and common curricula. In some countries, the higher education curriculum may be authorised by national authorities, but even then is mostly set by the "guild of professors". Most often, individual teachers seek authorisation to include their syllabuses from their immediate colleagues. In some areas of professional training, requirements set by academics and practitioners are imposed for reasons of safety or probity, while for subjects such as chemistry or physics, professional bodies may steer the curriculum.

– There is general consensus about the objectives of compulsory schooling. Higher education's purposes and mandates are multiple and under constant pressure to change as scale and client groups change. Its very definition has become unclear.

– While schools have many tasks, *e.g.* teaching and learning, pastoral and caring functions, and community functions, these are part of one structure. By contrast, the tasks of higher education – research, scholarship, teaching, consultancy and community functions – generate different forms of knowledge and of sponsorship and institutional organisation. The multiplicity of functions is reflected in the larger size of HE institutions and their complex organisation.

– All educational institutions are susceptible to influences/challenges from the outside world, particularly the economy. HE faces particularly strong demands to make its teaching, research and development (R&D) and screening activities relevant to the needs of society and the economy.

– Schools are largely hierarchical. HE institutions are run by combinations of hierarchical and collegial management, although the former has become stronger.

– Schools are subject to external evaluation, testing and inspection. Higher education has mainly been evaluated by peer review, but it undergoes external review and assessment for content, quality, outcome and process. In this respect, it is being drawn closer to schools.

– Compulsory education has always been unequivocally steered by the state. In many countries, HE has had considerable freedom, although degrees of state control vary and are changing.

The differences outlined above may explain why HER emanates from groups that are separate from those working on school research and sponsored in different ways.

The impact of policies on higher education research

The modes and content of HER are conditioned to some extent by changes in HE policy. The "nationalisation" of higher education – taking control of HE as a key policy area – affects the direction and control of HER. Alongside the academic objectives of disinterested enquiry and a critical approach that contributes to creating and testing theory, consultancy and short-term analyses of practical policy problems have increased. Here, sponsors primarily set the objectives, there is little opportunity for negotiation, and researchers are selected on criteria in which research excellence may not be very prominent. Some policy-directed research may reach publication, but on conditions set by sponsors. The major centres seek to combine independent and mission-orientated research programmes but find it difficult to secure a continuing flow of untied resources. Some of the policy pressures are:

– Governments now insist that institutions be efficient, with stronger managerial systems and evaluation. This has created an academic industry of its own: the large body of literature on quality assurance includes both prescriptive and impact studies.

– Many systems have attempted to change the teaching agenda by reducing the numbers entering public sector employment, by inducing employable and enterprise skills, and by pursuing the objectives linked to the Learning Society. This has given rise to research impelled by the wish to implement the policies more successfully. A policy-driven UK initiative in this area, however, seems likely to produce projects which might be funded as critical independent research.

– There has long been anxiety about epistemic shifts affecting the generation and legitimising of knowledge (Elzinger, 1985). Challenges to the authority of discipline-based knowledge by the sociology of knowledge in the 1960s have been followed by waves of critical theory: hermeneutics, post-modernism and other types of deconstruction. At the same time, legitimacy has been increasingly extended to subjects emanating from domains of concern or social problems. On the other hand, instrumentalism has affected agendas. Many systems see attempts to redirect the research agenda towards projects likely to enhance economic performance (Henkel and Kogan, 1996). In the United Kingdom, the Foresight Initiative and a White Paper (1993) were explicit evidence of this trend. Within HER, as elsewhere, there is thus some tension between "objective" scientific criteria and relevance. It is unlikely, however, that knowledge rules, as opposed to research agendas, have changed.

Whatever the factors causing or influencing these changes – economic constraints and demands of the economy, ideological shifts about the purposes of HE, changes in views of the relationship between the state and public institutions in general – it is plain that policies have created concepts, styles and structures in tertiary education different from those that obtained when it was largely concerned with producing an elite and knowledge mainly concerned with academic scholarship. Traditional forms of research, scholarship and teaching retain their importance, but higher education is now seen as having many functions, professions, client groups, styles, reference groups and systems of control, management and governance (Kogan *et al.*, 1994). It follows that the knowledge relevant to running and developing higher education will be multiple in content, use, and ownership. However, research often follows changes and is not necessarily used in the creation and evaluation of policies.

Knowledge styles

It was noted above that relationships are assumed between different kinds of knowledge and the forms of its transmission and use. Positivistic knowledge is generally thought to fit most comfortably into linear or social engineering patterns of delivery. Critical and theoretical knowledge is assumed to enlighten and to enter policy and practice through "percolation". Applied research depends upon collaboration and interaction. These views should not be dismissed, but neither should the free will exercised by both researchers and users of research be underestimated. For example, a large-scale quantitative analysis of differential access to higher education on the basis of social class, gender or ethnic dimensions could lead to a policy decision to change structures, institutional and student finance and perhaps, even, quality assurance and curriculum. However, and more likely in view of recent history, it would seep into the policy consciousness through percolation and have largely indirect effects. Similarly, the critical thinking of French scholars that backed the Faure reforms of university government in France appears to have had an almost linear place in the evolution of policy.

Different disciplinary perspectives produce different views of the policy agenda and of ways of treating it. Much of the higher education research that has affected policy has come from quite different traditions in sociology: studies of social structure that affect access to higher education; studies in sociology of knowledge that affect institutions' internal power and authority structures; studies of institutional structures which have shifted from celebrating the individual academic and the basic unit to management and quality studies. Economists might produce an entirely different vision of what regulates, or should regulate, student flows and higher education outcomes.

In terms of the three modes of knowledge, the positivistic mode may not appeal to many leading higher education researchers, but it has returned to favour among policy makers. "A consensus is emerging that there is a need for pluralism of approaches to educational research (...). In this holistic view, there is both 'good' and 'bad' positivist research, as well as 'good' and 'bad' qualitative research" (OECD, 1995). As indicated above, much research on higher education is narrowly targeted and time-limited, funded by government agencies, and directed towards a specific policy problem. It is often carried out by commercial consultants rather than academics. At the same time, some governments (*e.g.* Finland and the United Kingdom) have increased their own data-gathering capacity to the point where detailed knowledge about costs, outputs and judgements of quality is available to both government and institutions. All researchers find these contributions useful, even if they criticise their provenance.

Quantitative methods can be and are used to analyse process. For example, it is possible to determine from published UK data the impact of changing resource allocations on individual units (*e.g.* the kind of staff deployed in various years). Interpretative research, however, remains the method of choice for matters such as changing modes of government, the impact of reforms on the curriculum and research agendas.

The stage of development of HER plays a role. Van den Daele *et al.* (1977) identify three phases of discipline development: exploratory, paradigm articulation and post-paradigmatic. They assert that in the first and third phases problem orientation and discipline development are compatible. Before paradigms are established, functional research can be an input into the discipline. But when the development of theoretical models begins to crystallise, the research programme is usually dictated by "internal" needs. In the third stage, when the basic explanatory models have been tested, co-ordination with problem-oriented research may be possible. From this point, research may apply the basic theory. Higher education research, if, indeed, it is ever likely to create paradigms, may generally be assumed to be in the first phase. This may make researchers less eager to collaborate with policy-related sponsors.

The flow of critical research remains strong. In particular, sociological accounts of higher education as a distributive system, political science accounts of centralisation and decentralisation and the growth of "managerialism" in universities provide a critique of present policies largely based on disciplinary concepts. Much discussion of selectivity in research funding and the quality movement (*e.g.* Jenkins, 1995; McNay, 1996; Kogan and Henkel, 1996) has taken a critical perspective. Recent attempts to conceptualise and produce programmes for the Learning Society have also offered a critical perspective on existing patterns of teaching and learning. It is difficult to find examples of the third category of knowledge, applied research. For the most part, it is assumed that enough is known about what will work once a policy is specified.

Knowledge requirements

The characteristics of higher education affect the nature of the knowledge required to develop and evaluate higher education in terms of systemic policy making and management, for institutional policy making and management, relationships between higher education and the needs of society and the economy, development of its main functions: teaching-learning, research and scholarship, consultancy and community functions, and evaluation and monitoring of its different functions.

Policy making and management require knowledge of systems and institutions in order to determine trends in costs, access and, where possible, outcomes. At the same time, knowledge of what is important at the working level should be included in systemic analyses. Both conceptual and empirical enquiry into the nature of learning is essential if governments are to succeed in their attempts to encourage the inculcation of transferable and employable skills. The policy move towards selective research funding should take account of the prolific research on its unintended consequences and of assessment exercises (McNay, 1996; Henkel and Kogan, 1996). Important research has already been conducted on factors that encourage productivity and research (*e.g.* Pearson *et al.*, 1990; Kyvik, 1991 and 1993; Johnston *et al.*, 1993).

The following section looks at different levels – international, national, institutional and professional-individual – in an attempt to identify problems, the nature of the knowledge that might contribute to their elucidation, and the sources of such knowledge.

Knowledge about and for the system

The international scene

National systems are increasingly concerned with the international higher education scene, and stated national policies show considerable convergence, some of which must be due to imitation, *i.e.* transmitted knowledge. Research in many areas can fruitfully be conducted comparatively by researchers from different countries. As the language and conceptualisation of policy issues are now common to different national systems, international examples must be a starting point for many policies. Some research is explicitly directed to trans-country issues such as faculty and student mobility (*e.g.* Teichler, 1994).

Much fruitful international co-operation and interchange arises spontaneously. Individual academics communicate and increasingly work with others; this is a key variable in productive research (Kyvik, 1991). International associations such as the Consortium of Higher Education Researchers (CHER) and the European Association of Institutional Research (EAIR) promote the exchange of knowledge. Intergovernmental bodies such as the OECD and Unesco help countries to exploit research findings for policy analysis, and, in circulating knowledge and ideas, help set the future research agenda. OECD country reviews are a major source of information and insight into different systems, and the development of thematic reviews may enhance comparative knowledge of higher education. The OECD's Institutional Management in Higher Education (IMHE) project disseminates both research knowledge on systems and institutional management and practitioner experience. The European Union increasingly addresses educational issues and seeks help from the empirical knowledge base which international organisations are already establishing and helping to enlarge for educational policy making.

An OECD report (1995) has suggested ways of strengthening international R&D dimensions in education and training:

- Create an international market for R&D.
- Establish international bidding procedures so that the best equipped researchers, from whatever country, are appointed, as the Swedish national authorities already do. This would also enhance the dissemination of knowledge and skills.

- Look for forms of international collaboration, particularly when a comparative perspective would be useful.
- Pool resources wherever beneficial.
- Establish forums for problem identification.
- Create a presumption that all researchers should read at least one foreign language.
- Establish an international knowledge base through networking, conferences, shared projects and training events for younger researchers (the CHER has set a good example).
- Engage the interest and sponsorship of multinational firms and organisations with an interest in generating workforces able to work in more than one country and to refresh their knowledge and skills as employment and social institutions change.

More directly, it is important for systems to know how they compare in terms of: expenditure on higher education; human resources (staffing policies are largely neglected and will be of concern as international academic labour markets grow and changes in higher education require redefinition of staff preparation; see Kogan *et al.*, 1994); access rates, differentiated by social class, age, sex and part- and full-time recruitment patterns; outcomes of trained graduates; R&D outcomes. It follows that national statistics and other data should be collected in forms that make international comparisons possible.

As the principal source of statistical data, the national authorities rely on the data provided, *pro forma*, by institutions or by other parties such as employers. Data quality varies greatly: in some countries, there are many "inactive" students who inflate access figures and distort the planning for allocation of places and resources to institutions. Some institutions do not know how many students are on their books. In countries such as Greece, student data are complicated by the large proportion of students studying abroad.

While such data must be "hard", they should include analyses of the quality and processes of education offered, particularly as free access between countries becomes more common. They are best created by adequately funded independent researchers who could also exploit the judgements in official evaluations.

National knowledge requirements

HER has shifted attention from national situations to more general reflection on the nature of higher education and to analysis of the problems faced by systems and of policy implementation (Teichler, 1993). In the mid-1980s, there was a shift from concern about inputs to concern about outcomes (Ruin, 1984) as exemplified in research on performance indicators (*e.g* Johnes and Taylor, 1990; Cave *et al.*, 1997). More recently, there has been a move towards concern with graduation and employment rates and with impact (of general policies and different curricula). A flow of independent research also makes it possible to look at HE comparatively and critically in terms of the theory of public institutions.

A remaining concern is how far disciplined enquiry is useful to policy makers. They make sense of conflicting demands by reducing the number of facts and concepts they handle in order to be able to take action. Only the most far-sighted policy maker is disposed to encourage complicating facts and concepts.

Policy makers need data that are useful for international comparison when planning and evaluating the effects of their programmes. Apart from needs listed above, they require:

- Well-founded perspectives on the changing educational populations in terms of size and socio-economic and ethnic make-up and of the economy, which nourishes the educational system and expects contributions from it.
- Insight into the educational wants of the multiple stakeholders. A needs analysis may require a quantitative framework stating demographic developments, economic projections and forecasts of demand and be conditioned by "softer" data incorporating analyses of shifts in stakeholder demands for different services and feedback from users which gives an idea of the impact of policy.
- Accounts of patterns of organisation supporting or controlling educational practice and the other higher education functions. Many national authorities specify or give guidance to institutions on

internal governance as they release central control in favour of stronger institutional management. Several dimensions of such studies could affect thinking about statutory provisions for the governance of institutions.

– Evaluation of policy impact. Have policies changed the HE teaching and research agenda? Have they affected epistemic identities? (Henkel, forthcoming). Costs and benefits of different policies. What are the costs of reform and who benefits?
– Views of what works or what might work in education. What kinds of curricular, organisational patterns and differential applications of resources might affect the propensity of HE systems, institutions and practitioners to work more effectively?
– Information on demands on the system in lieu of information derived from pricing mechanisms. Educational research can provide information about changing clients' needs and wants and the extent to which education is perceived as meeting them.

In some countries, governments publish statistics on the detailed functioning of institutions, even departments. The United Kingdom's Higher Education Statistics Agency provides data that is very useful to system and institutional managers. However, data which have caused policy changes have often emanated from independent research groups, *e.g.* data indicating differences in take-up by social class.

Other data may arise from governmental requirements to evaluate performance. However, evaluations are not generally used in needs analyses or policy planning. They are used as corrective mechanisms in institutions or affect, in a minority of countries, the allocation of resources.

There is an enormous potential knowledge-gathering agenda for those who run HE systems. The quality and sophistication of the data now available vary greatly. Some countries and institutions can exploit data to evaluate and change policy but others have a long way to go.

Evaluation

National evaluation has generated much knowledge. Direct and regulatory controls have been replaced or complemented by the normative influence of evaluative judgements, and some governments use evaluation to achieve key objectives: control of public expenditure, changes in public sector culture, shift in the definition of public and private spheres of activity, and implementation of management criteria and expertise. Central to such evaluations have been linear-rational or closed-system models of decision making "in which unambiguous objectives are established, action upon them flows in predictable ways through established implementation structures, outcomes are monitored against them and objectives themselves may, in consequence, be reformulated" (Henkel, 1991). Evaluation has, however, produced enormous amounts of data on teaching and research quality in departments, quality assurance in institutions, with increasingly long times series, at least where systems are often evaluated, as in the United Kingdom. If, at the same time, independent knowledge system can be produced, the understanding of how total systems, institutions and academic levels could be improved.

National authorities require several types of knowledge. HER is better thought of as disciplined enquiry which encompasses research, development, applied research and evaluative studies and consultancy (Cronbach and Suppes, 1969). There is also ordinary knowledge (Cohen and Lindblom, 1979). Each type can be used, with two reservations. Knowledge must conform to academic criteria of evidence, logic and demonstrability, except perhaps the ordinary knowledge generated by journalists, politicians or opinion polls which may be objectively "untrue" but still relevant to the policy stream. Quantitative data are necessary for analysing present and determining future policies and are often a derivative of transactions between government and institutions. Almost any type of knowledge can be applied, add to the stock of knowledge or be used critically, depending on the purpose of the research, the identity of its sponsors, and how it is written up and disseminated.

Knowledge for institutions

Knowledge required by an institution depends on its view of its place in higher education and society. In an ideal world, all institutions would be interested in and benefit from the research activities. In practice, HE researchers find that academic leaders often make uninformed generalisations about subjects on which research evidence is available. Yet it must be recognised that most independent research will at most illuminate or have a percolative effect and that some of the most useful R&D in the form of enquiries or development work directed to helping the sponsors meet their objectives will be nearer consultancy than research.

Taking a somewhat minimalist view, one can look at the main institutional functions and determine the knowledge that might help them be performed most effectively. Some are those noted above for the system as a whole, but R&D can also meet particular institutional needs. A selection of possible themes follows.

– *Institutional portfolio and needs assessment*. All but the most privileged or controlled (*e.g.* military academies) institutions need to assess their clients' potential demands and needs in terms of the changing nature of the size and socio-economic and ethnic make-up of their educational population and the local economy so as to create an institutional portfolio. The growth in some institutions of functions concerned with marketing, promotion of fundable research, quality and the like testifies to a need for such positivistic and targeted knowledge. The national economy is the unavoidable frame for the institutional economy. Needs analysis could be conditioned by feedback from users on the impact of institutional activities which could affect teaching, R&D, outreach, consultancy and efforts to reach what now must be treated as markets as well as the planning for future staffing. This kind of knowledge might be generated or collated, when there are already good local census and other data, by trained administrative or planning staff, by the relevant academic departments of the institution, or by researchers or consultants employed for the purpose.

– *Internal management and governance*. Institutions need to decide how powers and functions are to be distributed: composition and powers of governing bodies, relationships between senate and other governing bodies and rectors, relationships between deans, heads of departments and individual academics, interface between academic leadership and non-academic administrators. There would then be a need for organisational negotiation, installation and development, which would concern university staff and academic leaders, with or without the help of consultants.

– *The costs and benefits of changing structures and policies*. The cash and opportunity costs of change are rarely charted and even less the impacts on working practices and perspectives. These would be tasks for university staff and, for impacts, for external research teams.

– *Staffing flows and academic markets*. Institutions should consider their potential staffing needs alongside preparation of portfolios and strategic plans. They need to bear in mind national and international studies of staffing demography which show disciplinary differences in academic labour markets and the importance of avoiding overly simple assumptions about recruitment and retirement patterns. They need also to address the issue of employment and adequate incorporation of temporary and part-time staff (Kogan *et al.*, 1994). This is primarily work for university staff, possibly with the aid of researcher-consultants. All universities can benefit from excellent national studies made or under way (*e.g* Pearson *et al.*, 1990; Davidson, 1991; Sloan *et al.*, 1990).

– *Academic productivity*. Recent studies (Kyvik, 1991; Johnston *et al.*, 1993) have shown that policy assumptions about factors that make for academic productivity are over-simplified. For example, incentives are confused with rewards. Once a fairly low threshold of size and resources is crossed, productivity levels off, so that increasing the size of teams or departments need not lead to increased productivity. Such findings could be the starting point for organisational development, which again might be usefully evaluated externally.

– *Curriculum development and teaching and learning*. Institutions in many countries are accepting the need to ensure that these functions are performed adequately. Some OECD country reviews reveal serious weaknesses in curriculum development and educational procedures. There are also pressures for curriculum reform, away from exclusive concern with discipline-based knowledge and towards more experiential and skill-based knowledge. There is already a considerable body of knowledge about how to evaluate and plan the curriculum as well as good material on the nature of the learning process. It will increasingly be needed, first to contribute to the base for monitoring teaching quality, and second to contribute to creative thinking about the function of education, a key task for leading academics with help from staff development specialists. These activities could contribute to the stock of case studies for modelling and theory development.

– *Quality assessment*. There is a great deal of R&D nationally and internationally on the purposes, power implications, techniques and impacts of different forms of internal and external assessment. Not all of the lessons of this work are taken up at institutional level.

Institutions must meet national requirements and develop the evaluative structures best suited to their missions and portfolios. It will be for them, for example, to decide on the extent to which evaluation by past and present students and their employers should be used. Models for such exercises are available in the literature. It is important, however, that institutions do not blindly follow the policy assumptions or technical structures proposed by evaluation pundits or funding bodies. Much current thinking is normative and research on impacts is relatively meagre.

Institutions do not have the resources and may not have the patience and interest to sponsor research as opposed to consultancy or evaluation. If they pursue their own objectives with the help of disciplined enquiry, they are likely to test at the same time received assumptions of both theoretical and empirical studies. For this reason, projects such as the OECD's IMHE provide a valuable forum for sharing institutional experiences.

Working academics

Working academics can benefit from the creation and diffusion of knowledge at the international, national and institutional levels. If they participate in staff and organisational development exercises, they should have access to current research on teaching and learning and patterns of governance. On the whole, as individual academics struggle to create syllabuses, assess their students, and deliver the curriculum, such knowledge is very little used (Henkel and Kogan, 1996). Nor is there much appreciation of the optimal conditions under which research and scholarship are carried out. There is also a lack of knowledge about leadership skills among the increasing numbers of academics who shoulder management tasks.

Many of these issues are initially the responsibility of senior academics who should accept a mentoring role for their more junior colleagues. Examples of research, some already referred to above, may illuminate decision making and mentoring by institutional and subject leaders:

– Academic productivity in research is not strongly related to resources or to unit size once a reasonable threshold is crossed (Johnston *et al.*, 1993). Uninterrupted time for work, social organisation of work, and opportunities to network within and outside one's department are more important. Incentives are often confused with rewards (Lonsdale, 1993) and may in fact be disincentives. (The productivity of Nobel laureates falls off after the award; Zuckermann, 1977.) These considerations should affect departmental allocation of tasks, award of sabbatical leaves and resources.
– Portfolio building is as important in departments as in institutions. Departments make the main working contacts with clients. To some extent, relevant data on external demand can be disaggregated from data collected by institutions (or *vice versa*) but specialist demands are best defined by specialists.
– Curriculum building is pre-eminently a departmental task. Learning theory can be a background, and findings on skills transfer, "deep" as opposed to "surface" learning, the relationship of formal to experiential learning are all relevant. Teachers must also be up to date on the curriculum content in terms of both academic and employment criteria.

Conditions affecting transmission and use

Institutional links

Connections between researchers and users are affected by institutional links. Countries differ greatly in recruitment practices and the background of policy makers and other research users and in the extent to which links are institutionalised. In Sweden, Norway and the Netherlands, where the connections are strongest, that relationship has been enhanced by the research experience of quite a few senior administrators. Many have degrees that involve a strong element of individual research.

Sweden has been at the forefront of rational planning, and the effect of research on comprehensive secondary education has been strong. In that country (Premfors, 1991), two-thirds of a sample of senior bureaucrats stated that research knowledge was of great or very great importance for their own tasks. Of those working in education policy, 75% thought research knowledge of great or very great importance. While 70% agreed that research results were rarely used, more than half of the top bureaucrats and two-thirds of R&D managers considered that obstacles to effective use of research were primarily located in decision making but only about one in ten blamed the research. They did not believe that research was irrelevant, poorly carried out, trivial or overly ideological.

The Swedish Board for Higher Education earlier hosted an eclectic range of research on higher education, science policy and the nature of knowledge, moving from pedagogy and policy application towards research on historical and philosophical issues and on the theory of size (Trow, 1991; Björklund, 1991). This did not weaken the close ties between social research and the central authorities. It was considered that researchers should place their competence at the service of building a better society but continue to be in complete control of their methods and results. Yet the take-up of the research is not clear. By the 1990s, research-based analysis was somewhat displaced by intuitive ministerial decisions.

The Netherlands offers a further example of mutual institutionalisation. A major centre at the University of Twente (CHEPS) was inaugurated because a minister, an education policy academic, wanted a new perspective on higher education. As in Sweden, central administration is characterised by open relationships between researchers and bureaucrats, many of whom have been researchers. There are biannual forums between CHEPS and the ministry, which uses international comparisons for policy making produced by CHEPS on access, student funding, diversity and other subjects. The two-year government HE plan is based on international comparisons.

These relationships undoubtedly depend upon the wishes and educational background of individual ministers and bureaucrats. Many are now long-standing. In Norway, over the last 20 years, the Institute for Higher Education and Research Studies can point to many policy issues which researchers have influenced.

Usability of research

Perceptions of the utility of HER varies according to the user's background and structural position. The nature of the knowledge will also affect its reception. In linear models, the process is driven by knowledge or problem definition, and research leads to dissemination and implementation. This idealised picture hardly ever obtains in higher education. Critical or theoretical research "may contribute to the long-term agenda for policy without, however, producing much impression on the here and now of policy and practice" (OECD, 1995). Positivistic research can serve HE's stakeholders but so can critical analysis.

The term "usability" thus implies a judgement on possibilities for using research. Caplan *et al.* (1975) outline three theories which may explain the gap between policy and research: in policy-constraint theory, policy is unable to handle the "rational" findings of educational research; in knowledge-specific theory, research is limited to a small framework of theories and empirical variables; and in "two-communities" theory, policy makers and researchers have different cultures, each with its own language, norms and values. Caplan *et al.* advocate the third of these theories and conclude that good communication is necessary. Bardach (1984) has noted how the reception by policy-makers of research is affected by the extent to which its utility exceeds or otherwise the cost of using it.

Mechanisms and conditions for transmission and use

What are the relationships between the producers and users of HER? The 1995 OECD report put it as follows: "The underlying power relationships can be various. Some researchers work within a managerial hierarchy in which they are subordinate to policy-makers; those working within government departments are obvious examples. Others work within a market in which the knowledge is purchased on the basis of competition with other researchers. For the most part the relationship is that of a market in which exchange and negotiation are the styles adopted. In such cases knowledge is exchanged for resources and legitimacy. Some market arrangements, however, allow for quite substantial tenurial rights which weaken the pull of the market and emphasise the need for well constructed negotiation and exchange."

The notion of "established tenurial rights" is particularly relevant to HER. Despite the massification of higher education, the power of established academic groups remains strong (Kogan and Hanney, 1999). The best-established groups are likely to be concerned with issues and depend on methods that derive from and can feed back into established disciplines. These exercise a normative as well as an institutional pull, it being academically desirable to advance conceptualisation in an established field of work. At the same time, a second culture, sponsored not only by governments but also by research councils in some countries, asserts the primacy of operational relevance.

The inherent indeterminacy of HE R&D as a producer of operational solutions is reinforced by changing disciplinary structures. There has been a shift from unidisciplinary to multidisciplinary and domain-based studies which results from and leads to new modes of knowledge integration (Gibbons *et al.*, 1994). These changes make the linear and social engineering models of R&D even less convincing. They may be reinforced by new organisational structures and research responsibilities. With targeted and negotiated research comes less emphasis on disciplinary research as the exercise of individual researchers' preferences. In contrast, there is the increasing determination of some policy systems to influence the research funded in the hope that it can provide impartial knowledge that can clarify or support arguments in favour of certain political decisions or practical solutions.

While producers and sponsors maintain a market relationship, the market rates of the commodities exchanged are changing in what are becoming increasingly directed public enterprises. The receiver of knowledge makes a rational decision about the cost of using knowledge and the nature of the receiver affects receptivity. The analysis could move on to examine the extent to which government departments have research managers who might act as brokers between researchers and government, or whether there are commissions or remit systems which, because they require authoritative data, have some commitment to the pursuit of knowledge.

Other transmission mechanisms relating to policy and practice include academic journals, conferences, and the media. The first two of these obviously facilitate exchange and testing of knowledge. The number of journals committed to the dissemination of HER has grown markedly over the last few years. Perhaps the most serious lack in this respect is the relatively little attention given to the need for rigorous review of major research as it emerges, with the result that knowledge is less cumulative than it might be. Published reviews also tend to concentrate on work published in English. In countries like the United States and the United Kingdom, there are journals dedicated to higher education, but their treatment of HER is minimal and based upon individual writers' interests rather than systematic attention to the field. There has also been a substantial growth in the number of conferences held by and for managers and administrators. To some extent, these involve academic presentations, but they are also concerned with the dissemination of knowledge generated by managers. The IMHE conferences and seminars and EAIR are probably the prime examples in Europe.

Summary and points for HER policy

Tertiary education differs in important respects from other phases of education and has its own distinctive knowledge requirements. As a result, R&D is undertaken by various groups of researchers who are sponsored in different ways.

There is no mechanical relationship between knowledge and policy. Some research has a percolative effect, as do changing perceptions of the authority of knowledge and the legitimacy of professional power within universities. This kind of movement, which only very indirectly affects national policy, may also reflect a more populist trend against received authority.

Major policy movements in HE, taken as a whole and with the possible exception of expansion, cannot be associated with the contribution of research-produced knowledge. Nowhere is the introduction of quality assurance based on evaluation of the existing quality of higher education; indeed, it has hit first and most strongly systems where standards were thought to be high. The drive towards marketisation has derived from ministerial ideology. The adoption of selectivity in UK research funding was based on assumptions about the importance of a "critical mass" which were not well substantiated by existing research.

The processes of higher education – the way academics perform research or students learn – have hardly been touched upon by research-based knowledge.

Institutional connections are at least as important as content or quality of research. Countries where research is said to have an impact on policy show the importance of open, continuing relationships institutionalised by government itself, between government and research groups. If agendas are negotiated between researchers and users, they stand some chance of being followed.

Negotiation of the use of knowledge with politicians is unlikely, but administrators working in government can be expected to join the negotiation if their needs are considered and included. Sponsoring and using research has opportunity costs. Where there is a close relationship, government and other sponsors need to ensure that researchers maintain an independent approach.

Research may take on prominence less because of its knowledge content than because it fits political pressures and demands, such as expectations that drive up university entries.

Is there an explicit receiver or brokerage function? Are there defined policy customers? The educational background of policy makers is also a factor.

Major policy changes have created new concepts, styles and structures in higher education; it follows that many types of knowledge are relevant to running and developing higher education.

International R&D for tertiary education can be strengthened by international market and bidding procedures, pooling of resources and creating common forums, establishment of an international knowledge base and the interest and sponsorship of multinational firms.

Different systems need to produce quantitative data in forms that make international comparisons possible. Independent researchers could also produce more qualitative data.

National knowledge requirements include data on educational populations and the economy, insight into educational wants and needs, accounts of patterns of institutional organisation, evaluation of costs, benefits and impacts of policies, knowledge of what might work in education.

Many quantitative data sets have come from independent research groups. A large range of potential research should be usable by systems managers and policy makers, institutions and the academic professions.

At the institutional level, it should be possible to draw upon both independent and national knowledge creation. Institutions may find it useful to generate applied research and consultancy to meet their particular needs: creation of the institutional portfolio, clarification of internal management and government, costs and benefits of actions, staffing flows, academic productivity, curriculum development and quality assessment.

At the level of working academics, research on academic productivity, needs analysis leading to departmental portfolio building and curriculum building are obvious areas of interest.

International and comparative research have particular value as a source of illumination and criticism.

Conclusion

The general case for sponsoring and using HER is convincing. HE absorbs large amounts of public and private resources, creating knowledge and training human resources for their own sake and for society and the economy. Understanding how HE works might help to improve it. HE activity presents a rich field for social science enquiry and for testing assumptions that underlie work in economics, political science, learning theory and the theory of knowledge and organisational theory. HER is thus justified in terms of utility and culture.

However, the use of HER is episodic and patchy. The concordance between policy and research agendas may be quite strong but the interaction weak. As a general rule, policy movements do not await disciplined enquiry. Nor do practitioners, who include some of the most intellectually confident members of society, consult HER before embarking on teaching or research. Yet many current problems could be illuminated if not solved by applying what is already known or could be uncovered by research. The problem is not that of researcher competence, but of institutional interaction.

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NOTES ON THE PRODUCTION AND USE OF KNOWLEDGE IN THE EDUCATION SECTOR

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Introduction

This paper examines briefly two important examples of the production of knowledge in the economics of education and its application to education sector policy. The first example involves the development and use of the concept of human capital and the rates of return to education as a tool of analysis. The second is the development of new knowledge concerning the way schools transmit learning to students. Economists categorise this knowledge as school "production functions", models that relate school inputs to student achievement. The third concerns the production and use of knowledge in understanding the relative effectiveness of private and public schools. In all three cases, academic economists (and sociologists as well as, in the third, political scientists) have been involved in knowledge production and have attempted to influence policy. In all three examples, international agencies involved in policy making also became involved in producing and using such knowledge.

For new knowledge to become part of the policy-making process, political and social conditions have to be prepared to receive and incorporate it. This usually means that this knowledge has to be consistent with "ordinary knowledge", *i.e.* people's beliefs based on everyday experience. It also means that the knowledge is useful in some larger political sense, mainly because educational policy, especially the kind of new knowledge produced by the economics of education, often has important distributional consequences. Further, the more the new knowledge becomes entwined with an overt political agenda, either institutional or national, the more heated the debate over such knowledge, the more the media become involved, and the more ideological the research itself becomes in response to politics and the media. In such cases, we may see politics shaping the new knowledge produced about education rather than new knowledge shaping policy.

Example 1. Rates of return

The concepts of human capital and rates of return as a tool for measuring the value of human capital net of the costs of producing it were mainly a product of university research. Cost-benefit analysis was developed by US government economists in order to measure the value of water projects and other infrastructure investments and to compare them with private investments. The application of cost-benefit analysis to education, however, was clearly situated in the academic enterprise. It represented a new way of thinking about labour as an input to the productive process. Human capital theory rejected the traditional classical economic concept of labour found in both Ricardo and Marx in favour of a much more complex formulation. In the human capital model, labour could actively enhance its own value by choosing to invest in education and training. Societies, too, could improve their productive capacity by subsidising investment in labour.

By the time Theodore Schultz began research on human capital in the late 1950s (Schultz, 1961), both the United States and the Soviet Union had been pursuing for more than a generation educational policies that implicitly or explicitly increased the productive value of labour. What Schultz and other economists did was to explain the role that education and training played in increasing labour productivity and to show how to measure its value. From the standpoint of existing policy, then, human capital theory did little more than justify what everyone "already knew". At the end of World War II, some 15 years before Schultz and others began writing about human capital, Congress passed the GI Bill, which rewarded returning World War II soldiers with the right to attend university at government expense. True, the policy was stimulated by fears that there would be no jobs for returning soldiers. But those who took the government up on their offer then and after the Korean War were aware of the benefits of university education. A university degree was identified in the popular consciousness with access to higher paying and higher status jobs well before academics produced the new knowledge that legitimised the human capital concept.

Resistance to the concept of human capital came not from "ordinary knowledge", but from educators. In the 1950s, 1960s, and later, educators opposed the underlying idea of human capital because it "reduced" education to "value in the marketplace" rather than value in itself, *i.e.* learning for learning's sake. Rather than contradicting everyday experience, then, the human capital concept challenged a competing (ancient Greek) ideal of "education for itself" which was held up as an antidote to the crass materialism of modern life. With modernity reaching its apogee just as Schultz was introducing human capital to the American Economic Association, idealistic educators had little chance. Modern materialism and human capital were made for each other. Besides, the human capital concept seemed to give policy makers a powerful tool for reducing inequality at a time when economic inequality was a major world issue. In the United States, the Civil Rights Movement was in full swing and John Kennedy was committed to reducing poverty. Communism was feeding on the vast differences in economic development between rich nations and poor. Here was a theory that allowed governments to intervene actively to improve labour productivity and wages of low-income groups. It was a theory that not only offered a rational explanation of inequality, but also a capitalist solution to it.

That being said, the tools that Schultz and others stressed for analysing human capital were not particularly useful to policy makers. For example, educational planners in the 1960s, who had begun to use Soviet-style manpower analysis to project government investments in different levels of education, resisted rate of return analysis. They could not understand how it would help them make accurate estimates of government spending on schooling. Rate of return estimates might indicate where to invest but not how much.

Despite these various forms of resistance, human capital and rates of return entered the policy-making arena, although they were never directly used for educational planning and the details remained almost entirely academic discussion points. Rather, human capital entered the consciousness of policy makers as a way of thinking about education. Once educators realised that the human capital argument generally helped the cause of expanding and improving education, they adopted it. Much the same can be said for rates of return. Although this tool was almost never used for educational decision making as such, it was often used to make the case for investing in education, particularly since ministries of finance in most countries held the public purse strings. And, of course, beginning in the 1970s, the World Bank made a fetish of rates of return to education as a justification for increased lending for education projects. Every education sector country report had to include measures of rates of return.

An interesting aspect of how and why the World Bank focused on rates of return was the argument George Psacharopoulos made at the Bank over a number of years (see, for example, Psacharopoulos, 1985). He argued that rates of return declined as the level of education rose, that the rates of return to primary education were extraordinarily high, and that private rates of return to university education were high but social rates were low. All this suggested that greater public sector investment in lower levels of schooling and privatised spending on higher levels were consistent with increasing economic growth and equity. The idea that one could invest in education in a way that improved both growth and equity was a politically powerful tool in the hands of an institution that was concerned with legitimacy in developing countries and in meeting opposition from the left in developed countries.

These ideas slowly became internalised in policy making, so that now, most politicians around the world will argue them without really understanding the data, how rates of return are calculated, or whether these stylised facts are even correct. However, the fact that powerful lending institutions and politicians from both ends of the ideological spectrum say that these concepts are empirically sound has made them policy reality. Policy makers have also justified changes in educational finance on the basis of these ideas. In many countries, public universities charge fees or much tertiary-level education has been privatised. Most educators seem to be convinced that investing more in primary education and improving primary education have a higher social payoff than investing in secondary or tertiary education and that investing more in education, particularly primary education, can have a powerful effect on the reduction of income inequality. All of these ideas are subject to serious question. For example, from the very beginning of the human capital discussion, it was clear to economists that returns to education were complemented by physical capital investment. Yet, much discussion of human capital has come to focus on the causal value of human capital as an engine of economic growth. On the other side of the coin, economists often choose to ignore, in practice, the value of public investment in human capital when they recommend macroeconomic policies. Now that communism is no longer a threat to Western hegemony, expanding public spending on education is less urgent than it was in the 1960s, and this has had an impact on economic policy making. For their part, educators have not been fully won over to accept economists' "materialisation" of education. In academia, educational researchers usually ignore the "material" approach to educational policy. A careful scrutiny of recent educational research would reveal relatively little influence of human capital theory, cost-benefit analysis, or "material" variables in explaining educational policy options.

Despite the continued marginality of "material" notions of education in most educational research, the human capital concept is deeply ingrained in the public consciousness, in academic thought, and in the world policy-making community. One obvious reason why these ideas became so deeply ingrained is that they are consistent with public experience. Indeed, increased income distribution inequalities worldwide make even clearer to the public that those with more education do better economically than those with less. A second reason that they became ingrained is that economists were able to produce hundreds of articles and books measuring rates of return to additional schooling from increasingly more detailed data sets that measured individual earnings, work experience, socio-economic background, and school achievement. Such empirical studies not only supported earlier notions of human capital but solidified the connection in the public consciousness between education and economic payoff. A third, less obvious, reason is that the human capital concept served political and financial goals in a period of considerable economic problems and increasing income inequality worldwide. The following two examples reinforce the notion that academic research on education filters into policy consciousness only when it is consistent with "ordinary knowledge" and when it is "politically appropriate" for the particular time and place.

Example 2. Production functions in education

When James Coleman did his famous empirical study on equal opportunity, now known as the Coleman Report (Coleman, 1966), its policy impact was immediate even though the statistical analysis was quickly criticised by a number of young economists, including Samuel Bowles, Henry Levin, and Eric Hanushek (Bowles and Levin, 1968; Hanushek, 1971). The effect of the Coleman report took an interesting form. Coleman found that in US education, although socio-economic background was much more important in explaining academic achievement than what went on in schools, his results also suggested that black students did better in integrated schools (this was an early identification of "peer effect"). In the context of the 1960s, this was what infused policy. School integration through bussing in northern US cities, where residential segregation rather than "official" segregation created separate schools for black and white students, was justified by Coleman's findings. Twenty years later, blacks themselves had second thoughts about "forced integration", even though "peer effect" was showing up again in hierarchical linear production function models as highly significant in explaining school achievement. In the 1970s, school desegregation in northern cities was very much on the legislative agenda, so "peer effect" was used to justify bussing. In the 1990s, low-income blacks in inner cities wanted more choice, so the positive peer effect finding has been used to justify using vouchers for them to attend Catholic schools. In each case, the new knowledge found its application in policy because it seemed to reflect an interpretation of everyday knowledge (children of every level of ability seem to do better in school when the school has a higher fraction of high achievers) and because it fit and still fits a prevailing political climate. In the first round, urban public schools were considered fertile ground for raising blacks' achievement when there was a sufficient population of white children. In the current political climate, urban public schools are considered a wasteland, so the same results are used to justify sending children to private schools, or at least to schools of their choice.

Coleman's work also spawned a mini-industry of analysing the relationship between school inputs, students' socio-economic background and their academic achievement, as measured by test scores. Having participated in that industry and personally encountered the difficulties of both modelling and estimating educational production functions that really measure educational processes, the author of this paper is amazed at how much weight policy makers accorded the results. The fact is that, in education, production function models were grounded in neither learning theory nor organisation theory, yet because they produced statistically significant results in some cases, they were and continue to be used by academics to make the case for certain educational policies.

Such input-output models were estimated throughout the 1970s and 1980s for many countries (see Hanushek, 1986). Individual countries' educational policy makers, including in the United States, did not use the detailed results, in part because they were not overwhelmingly convincing. However, certain details did enter policy-making beliefs: for example, that class size made little difference in student academic achievement unless it dropped to very low levels, or that increased spending on education did not raise student achievement, largely because most additional money went to teachers' salaries and paying teachers more did not result in more student learning.

Again, the World Bank played an important role in carrying the production function into the world policy arena. Bank researchers argued that textbooks were particularly cost-effective in raising test scores in places where children lacked textbooks, that class size made little difference in raising student achievement, that pre-service teacher training had little effect on student achievement, and that in-service teacher training was much more cost-effective than pre-service training.

Some of these results became policy mantra at the World Bank and in the educational policy community in the United Kingdom and the United States (and perhaps also in Australia and New Zealand) but not in continental Europe. Why so? It seems likely that it was largely because the production function results, at least as interpreted by analysts such as Hanushek, fit the neo-conservative political ideology of governments in the United Kingdom and the United States in the 1980s and early 1990s. They liked the idea that spending more on education, particularly on teachers' salaries, did not produce higher achievement.

Since the World Bank was very much attuned to that ideology and, during the 1980s, was pushing structural adjustment policies in the developing countries, it incorporated this new knowledge into its policy thinking. Bank analysts supported and continue to support the notion that improvements in educational quality can be achieved without increasing public spending on education. They argued that since class size, a major determinant of educational costs, did not have to be reduced below 45 students per teacher to maintain educational output, then countries should keep class sizes as near to 45 as possible (for example, Lockheed and Hanushek, 1988). If teachers' pre-service training was not an important factor in student achievement, teachers with less education should be hired at lower salaries. Some of these policies were actually implemented in countries with severe financial problems, where the World Bank's lending conditions could enforce them. Combined with privatisation of higher education, public spending per student was actually driven down in many developing countries. Whether this had an effect on quality is not clear, since no effort was made to document the impact of these policies on quality.

Overall, the policies suggested by production function estimates were not implemented, even in the United States. Real spending per pupil in the United States rose significantly in the 1980s. Class size continued to decline in almost every state. Pupil/teacher ratios declined in many other countries worldwide, including some, such as South Korea that had been held up by the Bank as a example of how a country could have large class sizes (a pupil-teacher ratio of 70) and produce high achievement. On the other hand, in some countries, such as those in the former French West Africa, where class sizes were often three times the maximum number of students per teacher recommended by production function studies (45), class size did not decline with World Bank policy intervention.

There is an important lesson to learn from the failure of policy makers to prevent declining pupil-teacher ratios in most countries despite academic research arguing that class size effects on achievement were insignificant for all but very small classes. Since that new knowledge accorded neither with parents' nor with teachers' beliefs about the effect of class size, countries with rising per capita incomes were inclined to allow class sizes to fall. California was a notable exception, as it had self-imposed limits on educational spending. But California test scores have fallen relative to those of most other states, and rising class size has taken much of the blame.

It is always amusing to ask one's friends at the World Bank why they send their children to private schools. Among the first three reasons, they always list class size. This shows that, personally, they do not believe the empirical results they impose on others. And this makes sense. From the standpoint of a ministry of finance, children should be added to a class until the marginal. Child is not learning anything (the marginal product equals zero) provided that the marginal cost of adding more children is also zero (the family must pay for all school supplies). This maximises the use of the money spent on the teacher and the facilities. From the standpoint of the family and the child, however, the view of educational productivity is quite different. They want a much smaller class size because their marginal cost is far from zero and they therefore want much higher than zero marginal productivity. Similarly, any teacher who feels (or is made to feel) responsible for children's learning wants his or her marginal productivity to be much higher than a ministry's desired level. Thus, class sizes have historically been driven down.

Recently, another form of new knowledge, namely experimental results in Tennessee from random assignment of primary school students to classes of small and normal size (Finn and Achilles, 1999) show that reduction of class size does improve student achievement. These results are also controversial (they were, for example, criticised by Hanushek, 1999), but they have been borne out by further follow-ups of students (Nye, Hedges and Konstantopoulos, 1999). It seems that the effects are large. Placement in a class of 15 rather than 25 for several years produces an average test score increase of about 0.4 standard deviations. More important, this new knowledge not only accorded with popular views of good education, it fit the political mood in a booming economy looking for ways to improve education. The Tennessee results were seized on by the governor of California as soon as large amounts of tax revenue became available. Facing massive criticism because of low achievement scores by all groups of students, the governor reduced class sizes from 27 to 20 in all of the state's K-3 classrooms, a tremendously popular but expensive policy measure with far-reaching financial consequences. It is telling that most education policy analysts were appalled by the suddenness and size of the move. Yet, it was consistent with the axiom that when it comes to implementing research results, politics rule. When the results do not coincide with the political mood or the wishes of the powers that be, instead, it is highly unlikely that they will be implemented or even appear in political rhetoric.

Textbook policy in developing countries provides another example that reinforces the validity of this axiom. In the case of textbooks, new knowledge from production function research was often not implemented even when results accorded closely with "popular knowledge". Knowledge on the cost-effectiveness of textbooks has always been much less controversial than research showing negligible effects of class size on achievement. It is fairly obvious that books are crucial for teaching reading and that giving students books would make reading and maths scores rise. Furthermore, the technology for producing cheap, effective textbooks for every one of the world's pupils has long existed. The costs are well within every country's financial capacity, and even most families could afford to contribute to the cost of low-priced books. However, textbooks are controlled by copyright. Textbook purchases and distribution in many low-income countries are the source of "arrangements" between foreign textbook publishers and local government officials. The World Bank, with all its financial power, and even with the results of production function studies in hand, has not been able, and perhaps not even willing, to break the monopoly of European textbook publishers on textbook distribution. Evidently, the political effectiveness/cost ratio of implementing widespread cheap (or pirated) textbook distribution has been too low, despite potentially extremely high value in terms of student achievement.

Example 3. Private versus public schooling

In the 1980s and 1990s, politicians have found that criticising public education guarantees that they will gain attention without much political cost. In the United Kingdom and the United States, as well as in the World Bank, the Inter-American Development Bank, and even the OECD, the questionable effectiveness of public education for low-income pupils and the onerous weight of public bureaucracies in education have been the basis for continuing criticism of public education. Politicians, conservative think-tank writers and economists in international agencies have all cited alleged "shortages" of resources plus "inefficient" public bureaucracies as good reasons to begin looking at privately run schools as a logical alternative to the "public monopoly" on education.

In the United States, this has produced a great deal of academic research by economists, sociologists, and political scientists. Much of this research has concluded that private education is more effective and more cost-effective than public education and that more market-driven education would improve student achievement. Again, James Coleman had a hand in this trend; in 1983, he published a study that purportedly showed that Catholic schools in the United States produced higher student achievement than public schools catering to a clientele of a similar social class. A study by Chubb and Moe (1990) used political-sociological organisation theory as the basis of empirical estimates that also seemed to show that private schools were more likely to have the organisational characteristics that produced high student achievement. Bryk *et al.* (1993) compared Catholic and public high school education using the same longitudinal data (high school and beyond) as Chubb and Moe. They found that Catholic high schools produced somewhat higher achievement gains than public schools when students' socio-economic background was controlled for.

However, such studies were not limited to the United States. World Bank researchers also did a series of studies on Thailand, the Philippines, and the Dominican Republic, making the argument that private education was much more cost-effective than public education (Jimenez and Lockheed, 1995).

Since these studies confirmed what many believe in the United States and many other countries – that private schools are more effective than public schools – and also suit the goal of many conservative politicians to privatise social services, there has been a rush to implement these results through voucher plans and charter schools. All such plans effectively allow private schools to receive the same amount of funding per pupil as public schools or allow public schools to privatise their management. Economists at both the World Bank and the Inter-American Development Bank have used such new knowledge to push hard for privatising education in Latin America, Asia, and Africa.

Results concerning the greater effectiveness of private or privately run education are highly controversial. Recent academic research battles concerning a experimental voucher plan involving only five non-religious private primary schools in Milwaukee, Wisconsin, or a few Catholic schools in Cleveland show how difficult it is to correct for selection bias in such studies and thus to estimate educational value added correctly (Rouse, 1998). They also show that politics play a primordial role in making, presenting, and interpreting such research results. The exchanges were vitriolic (therefore pleasing to the media) and allowed every interest group to choose the results it liked best.

The World Bank's studies have also been criticised. Another economist consulting for the Bank, Mun Tsang, showed that the cost estimates for Thailand were incorrect and biased in favour of private schools (Tsang, 1995). The Bank's showcase voucher plan, in Chile, has now been reanalysed on the basis of excellent data. These new results show that private voucher schools are less effective than public schools and only slightly more cost-effective (McEwan and Carnoy, 1999)

Indeed, when all the data are carefully scrutinised and the rhetoric stripped from the studies reporting them, the most accurate way to describe the results is that the differences between student achievement in public and private education are small. Yet, this important new knowledge is obscured by the political ideology that surrounds it. It seems that the cause of privatising education and the cause of public education are much more important than the actual empirical results. It is true that the stakes are high. Government spending on education represents about 3-4% of world gross domestic product. Many see these vast public resources as a major opportunity for private profit. Others simply want to dismantle public education for ideological reasons. Yet others want to defend the economic position of public employees and public control over the socialisation of young people. Thus, new knowledge produced by academic researchers is right in the middle of a political struggle with significant economic overtones.

Since a basic tenet of neo-classical economics – that markets are more efficient than public agencies in delivering public services – has successfully seeped into the public consciousness in many countries (whether it is true or not), research results that reinforce that idea are much easier to sell than those that oppose it. In this case, however, the interesting observation is that since most parents worldwide still send their children to public schools, most parents are not politically committed to privatisation. Furthermore, in most countries, parents can exercise choice, and many private schools are already subsidised by public monies. Thus, public pressure for privatisation is not nearly as great as for, say, smaller class size or better teachers.

The very controversial nature of the issue is attractive to researchers on both sides, but because privatising the management of education with public revenues has become a major political issue worldwide and a policy issue in some international banks, there is a market (and therefore major funding) for new knowledge. In this case, the research is tailored to the cause, and again, politics is the driving force. But here, academics see an opportunity to push their research results into policy by producing results that meet certain political interests. Of course, researchers who support public education are also attracted to the fray. Yet, because the differences between public and private schooling are so small, somewhat louder voices on one side or the other can implement policies which they favour, using the version of new knowledge they prefer.

The role of the media in "mediating" new knowledge in a case like this is particularly important. The media often cannot interpret the complex statistical techniques used to estimate whether private or public education is more effective or efficient. Thus, researchers are induced to exaggerate their results. The media not only like controversy, they like clear results. Since the empirical results tend to be grey rather than black or white, the media advance a much clearer interpretation than is warranted, often convincing the public that some knowledge is much more definitive than it is and allowing policy makers to implement policies that fit their predetermined biases.

The danger in this example is that the production of new knowledge in the economics of education becomes tailored to researchers' own policy goals or to the policy goals of others rather than to the presentation of new knowledge as a goal in itself. In this sense, political biases lead to the creation of the new knowledge needed to justify policies that politicians want to implement, so that new knowledge is a product of politics rather than the reverse. Unfortunately, the fact that statistical techniques are much more sophisticated than the data available for examination for most issues makes this kind of new knowledge production easier than it might seem.

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THE PRODUCTION, MEDIATION AND USE OF PROFESSIONAL KNOWLEDGE AMONG TEACHERS AND DOCTORS: A COMPARATIVE ANALYSIS

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The most pressing need confronting the study of professions is for an adequate method of conceptualizing knowledge itself.
Eliot Freidson, 1994

Introduction

The are two grounds for undertaking a comparative analysis of the knowledge-base and associated processes of the medical and teaching professions. First, by examining the similarities and differences between the two professions, it should be possible to advance a generic model of a professional knowledge-base. Secondly, the contrast offers some indications of what each profession might learn from the other.

In this chapter, doctors and teachers are compared in relation to their highly contrasting knowledge-bases. Whereas the knowledge-base of doctors is rooted in the biomedical sciences, teachers have no obvious equivalent, and the attempt to find one in the social sciences has so far largely failed. Yet both professions share a central core to their knowledge-base, namely the need to generate systems for classifying the diagnoses of their clients' problems and possible solutions to them. Contrasts are drawn between the styles of training for doctors and teachers, with doctors having retained some strengths from an apprenticeship model and teachers now developing more sophisticated systems for mentoring trainees. In both professions, practice is often less grounded in evidence about effectiveness than is commonly believed, but practitioner-led research and evidence-based medicine have put doctors far in advance of teachers. Adaptations of some developments in medicine could be used to improve the systemic capacities for producing and disseminating the knowledge which is needed for a better professional knowledge-base for teachers. There may be aspects of knowledge creation and dissemination where teachers have a small advantage over doctors.

A generic model of the professional knowledge-base is proposed. The model and the analysis are then set within the wider context of the changing process of knowledge production.

Science and the professional knowledge-base

Qualified medical practitioners are universally accepted as a profession with relatively high levels of autonomy, prestige and privilege. Despite the many national differences in the political and institutional arrangements for the provision of health care that affect the social position and clinical freedom of the doctor (Freddi and Björkman, 1989; Hafferty and McKinley, 1993; Johnson, Larkin and Saks, 1995; Wall, 1996), they almost everywhere enjoy high social standing. Most school-teachers would like to be so regarded, and may even lay claim to professional status, but are usually seen to fall short of being full professionals. Unlike doctors, school-teachers lack the esoteric knowledge-base that is a key characteristic of professions (Larson, 1977).

The knowledge-base of doctors has shifted over the centuries. Today it is seen as essentially scientific in character, despite the considerable differences between medical specialties. Its convoluted evolution was deeply affected by the rapid expansion of the sciences in the 19th century. This did not always result in immediate changes to medical practices: there is often a lag between advances in basic science and changes in clinical practice, as progress in science first changes the conceptual background and medical understanding before impact on clinical practices emerges. Thus Harvey's discovery of the circulation of the blood in 1628 had no short-term beneficial effects on medical practice. Until the late nineteenth century, the application of scientific knowledge to medicine spawned quackery as often as genuine medical progress (Bearn, 1977).

> There was no convincing evidence, in the early part of the [nineteenth] century, that the physician trained in science had better results than the older physicians who were not thus trained (…). It was not at all obvious that a knowledge of, say, chemistry, enabled a nineteenth century physician to provide better health care (…). Medical science (…) had not as yet become translated into convincing practical results. There was no good evidence that long and expensive training in the medical sciences was the sole means of making effective doctors (King, 1982).

To use Ryle's (1949) terms, "knowing that" or *declarative knowledge* is different from "knowing how" or *procedural knowledge*. The latter does not necessarily need much of the former, and the former can be learned without having any effect on the latter. In the United States the reforms in medical education and training fostered by Abraham Flexner and William Osler, under French and German influence, strengthened the scientific elements in the knowledge-base provided for medical students but it was combined with hands-on clinical experience. Indeed, there was no good reason for doctors to increase their faith in science until it could be shown that such reliance would lead to better patient care.

> Faith in science (…) was not widely shared until the end of the nineteenth century, when scientists were first able to make an overwhelmingly convincing case (…) for the connection between scientific theory and research and utilitarian technological applications (Larson, 1984).

Whilst it is indisputable that advances in the basic sciences, such as molecular biology and pharmacology, have an impact on medical practice, it was not to the basic natural sciences as such that the changes in clinical practice at the end of the nineteenth century should be attributed, but rather to the emergence of clinical research and clinical sciences – the investigation of the symptoms and causes of disease and the development and application of therapeutic interventions – which created the crucial mediator between basic science and professional practice.

> The rapid rise in America's accomplishments in clinical science in the early 1900s can be attributed to the effort of a small group of men who created specialised, rapidly expanding positions and faculties for clinical research (…). There soon emerged the middleman of medical science – the full-time clinical investigator – who formed the bridge between the basic scientists on the one side and the practitioner of medicine on the other (Harvey, 1981).

In the preparation of secondary school teachers, the knowledge-base was taken to be their subject knowledge, or knowledge acquired through a university degree in the subject of the school curriculum they intended to teach. Such graduates have been permitted direct entry to school teaching without any teacher training, on the assumption that the art of teaching required no special knowledge at all, but simply experience. Knowing one's subject is a necessary but not sufficient condition for effective teaching, which also requires the acquisition of what has been called *pedagogical content knowledge* (Shulman, 1986), or the knowledge about how to structure the teaching of the subject so that students learn – which concepts are easy or difficult for students, which parts are better taught before others, how teaching relates to the teacher's understanding of what students already know, and so on. Various components of the teacher's knowledge-base has been suggested (*e.g.* Reynolds, 1989; Dill, 1990; Hargreaves, 1993; Turner-Bisset, 1999), but how they relate to one another and how they are acquired remains deeply obscure – which is also true of doctors and engineers (*Cf.* Carlsson, 1999).

Since, however, belief in progress and the authority of science developed together and were mutually reinforcing, not least in the field of medicine, it is not surprising that a knowledge-base for teaching should also have been sought within the rapidly developing social sciences, especially if modelled on the natural sciences.

> American social scientists are interesting because their faith in science as the engine of progress has been especially intense. From the outset they claimed to have established sciences before they were in possession of any body of scientific knowledge (Ross, 1984).

Oblivious of this last observation, but keen to provide the teaching profession with a stronger knowledge-base, those involved in teacher training turned to psychology, and later to sociology, for the facts, theories and concepts of basic social science which could be applied to educational phenomena, especially those of the schoolroom. And the legitimizing function of the social sciences assumed particular importance in the 1960s when in the United Kingdom the decision was taken that teaching should become an all-graduate profession and that primary school teachers should have a Bachelor of Education degree to match the Bachelor of Arts or Bachelor of Science of the secondary school teacher. Thus topics such as child development and the psychology of learning moved to the centre of the curriculum for initial teacher training.

Today it has to be conceded that the original promise of the social sciences was not delivered to education. Within a mere twenty years of the establishment of the BEd., confidence in the social sciences as the source of a professional knowledge-base had eroded, both among practising teachers and among politicians and critics of teacher training, though not among the teacher trainers. With the intervention of UK ministers of education in teacher training from 1984 onwards, the social sciences were progressively demoted and are today marginalised within teacher training.

The failure of the social sciences to generate a knowledge-base for teachers is explained largely by the inability to develop a persuasive educational equivalent to clinical science, which would serve as a powerful bridge between basic science and professional practice in a way leading to evident improvements in professional practice.

The core of the professional knowledge-base

It has been argued by Abbott (1988) that *all* professions (by definition providing a service to clients) have common features which, adopting an openly medical metaphor, he calls diagnosis, inference and treatment.

> Diagnosis and treatment are mediating acts: diagnosis takes information into the professional knowledge system and treatment brings instructions back out from it (...). Inference (...) takes the information of diagnosis and indicates a range of treatments with their predicted outcomes.

These concepts are as readily applied to what teachers do for students as to what physicians do for patients. Diagnosis has two elements. The first, *colligation*, consists of a set of rules deciding what kinds of evidence are relevant and valid in making a diagnosis. The second, *classification*, names the diagnosis by placing it within a dictionary of professionally legitimate problems. In short, clients present a problem of some kind – what kind of illness a is this? why is this child having difficulty learning this? – and the professional draws upon rules to decide if it really is a medical (or educational) problem, and exactly what *kind* of problem this is and how it is to be named.

The systems of colligation and classification apply also to the treatment: there are rules for deciding what treatments, which have their own system of classification, are relevant to the problem and which shall be chosen. The inference process – which I think is more appropriately classed as *professional judgement* – links diagnosis and treatment so that, wherever possible, the treatment is likely to resolve the diagnosed problem.

Within professions, colligation and classification systems betray their evolutionary origins and do not necessarily reflect an abstract, academic system of ordering diagnosis and treatment. In medicine, for instance, diagnostic systems may be based on pathology (muscular atrophy) symptoms (neuralgia) aetiology (amoebic dysentery) or the discoverer (Paget's disease) or a combination (P*aget's disease* becomes *osteitis deformans*). In education, the one sector which in these matters comes close to medicine is that of special educational needs or remedial education, where there is an evident influence from clinical psychology as well as a more explicit concept and process of both diagnosis ("What are this child's learning needs and what is affecting them?") and treatment ("What treatment is available to remove or mitigate the problem?").

In both education and medicine, I suggest, the classification systems for diagnosis, which is at the core of the professional knowledge-base, contains three dimensions:

- How common or rare is the problem?
- How major or minor is the problem?
- How easy (or cheap) or difficult (or expensive) is it to treat the problem?

Within both professions, problems arise in all possible combinations of these dimensions. At one extreme there are common, minor problems that are easy to treat – a minor cut, talking out of turn in the classroom – and at the other are the rare, major problems that are difficult to treat – Creutzfeldt-Jacob disease, an emotionally disturbed child with severe learning difficulties. Mastering these three dimensions of the core of the knowledge-base is the essence of professional learning and takes time and experience.

In medicine, to achieve high status one must be a demonstrably able practitioner with a high degree of mastery of the core knowledge-base. In their thirties, doctors often see themselves as overloaded with their formal knowledge-base and seek wider experience to strengthen their clinical know-how and professional judgement. A decade later, they return to their formal knowledge-base, feeling a need to keep up-to-date across the rapidly expanding state of formal knowledge in medicine. Doctors who diverge into administrative or academic roles risk losing their credibility among practitioners. Schoolteachers, after ten years' experience, put less emphasis on extending their formal knowledge-base, and seek opportunities for *reflection* about their experience. Although there is the same risk of loss of credibility to those abandoning full-time, front-line practice, there are relatively poor promotion prospects for classroom teachers. For higher status and pay, a teacher enters an alternative career path of manager, inspector, teacher trainer or administrator. Even mainline promotion to headteacher requires mastery of a different knowledge-base, as the recent introduction in the United Kingdom of the mandatory qualification for headship illustrates. By contrast, medicine announces clearly to all – including trainees – that continuing mastery and development of the practitioner knowledge-base is the principal source of prestige and promotion within the profession.

In some respects, devising systems of classification for both diagnosis and treatment is difficult for teachers, since they are not as heavily focused on the individual as is true in most medicine. Teachers routinely deal not with the individual child, but with the individual in the social context of the classroom, and also with the class as a whole: at the core of teaching is the skill of managing classrooms, not just individual students. Diagnosis and treatment are thus socially embedded in ways that are unusual in medical fields. In addition, in deciding a treatment for a learner the teacher has to decide not merely *what* to give the child (*e.g.* some curriculum content) but also *how* to do so (that is, a pedagogic strategy), for children are, one suspects, far more variable in their response to their teacher's treatment than are patients to their doctor's. Moreover, whereas most professionals, on first meeting their client, expect to focus immediately on addressing the client's problem and excluding material that is irrelevant to its diagnosis and treatment, school teachers will (unlike most teachers in higher education) want to focus on "the whole child" and his or her wider development, rather than merely on the immediate problems at hand. So medical systems of classification for both diagnosis and treatment are, in contrast to their equivalents among school teachers:

- More restricted in scope.
- More explicit and clear.
- More consensual among practitioners.
- More related to, or grounded in, science.
- More essential for effective practice.

Given the complexity of both diagnosis and treatment in education, it is arguably even more important for teachers than for doctors that they should have explicit and consensual classificatory schemes of diagnosis and treatment in order to generate a smoother and speedier methods of acquisition by novices of this part of the knowledge-base. Greater agreement on classificatory schemes might generate more focused research and text-books on teaching. Social science may well claim to be able to improve classification systems for the diagnosis and treatment of educational problems, and thus to furnish teachers with a powerful professional knowledge-base, but for the most part such conceptual schemes, only superficially and temporarily internalised, are largely abandoned, leaving residual traces, as novices quit their formal training and set about building up their professional knowledge-base through personal experience.

So social science has thus far failed to generate for teachers either professionally acceptable classificatory schemes or (as was once the case in medicine) to sophisticate pre-scientific schemes in existing professional practice. Teachers in regular classrooms in effect develop their own personalized classification systems and rules of evidence.

> Teaching has not been subjected to the sustained, empirical and practice-oriented inquiry into problems and alternatives which we find in university-based professions. It has been permitted to remain evanescent; there is no equivalent to the recording found in surgical cases, law cases and physical models of engineering and architectural achievement. Such records, coupled with commentaries and critiques of highly trained professors, allow new generations to pick up where earlier ones finished (...). [T]o an astonishing degree the beginner in teaching must start afresh, uninformed about prior solutions and alternative approaches to recurring practical problems What student teachers learn about teaching, then, is intuitive and imitative rather than explicit and analytical; it is based on individual personalities rather than pedagogical principles (...). One's personal predispositions are not only relevant but, in fact, stand at the core of becoming a teacher (Lortie, 1975).

Many teachers attest to the truth of such claims. New teachers gain much from informal socialization among experienced teachers, where there exists a professional common-sense knowledge that is not codified but works as a basis for professional use and for dialogue with colleagues such as a "difficult child" or a "learning difficulty". If the level of the language seems largely common-sensical, this is perhaps because

> (...) one of the most notable features of teacher talk is the absence of a technical vocabulary. Unlike professional encounters between doctors, lawyers, garage mechanics and astrophysicists, when teachers talk together any reasonably intelligent adult can listen in and comprehend what is being said (...) [and] the uninitiated listener (...) is unlikely [to] encounter many words that he has never heard before or even any with a specialized meaning (Jackson, 1968).

Because the development of a knowledge-base for teachers was supposed to proceed in linear fashion from the social sciences to application in educational contexts, teachers' professional or craft knowledge in use was not seen as itself worthy of serious study or formal codification. Indeed, it is arguable that the strong position that social science came to play within educational studies in the 1960s actually impeded the study and codification of teachers' craft knowledge (McNamara and Desforges 1978; Brown and McIntyre, 1993), even though here was a potential contributor to a knowledge-base.

There is, of course, a tension in all professions between codified professional knowledge and professional knowledge in use.

> The character of the abstract classification system is dictated by its custodians, the academics, whose criteria are not practical clarity and efficacy, but logical consistency and rationality. Professional knowledge consists, in academia, in a peculiarly disassembled state that prevents its use (...). The prestige [of a profession] reflects the public's mistaken belief that abstract professional knowledge is continuous with practical professional knowledge and hence that prestigious professional knowledge implies effective professional work. In fact, the true use of academic professional knowledge is less practical than symbolic (Abbott, 1988).

In medicine, novice doctors experience difficulty in transferring what they have learned from textbooks or lectures into usable knowledge that they can deploy in relation to the case at hand, for diagnosis and/or treatment. For novice teachers, by contrast, practical problems in classrooms are not usually perceived to be solvable by drawing upon the psychology of education or child development, that have been studied in the university-based initial training. On the other hand, teachers pay a heavy price in that the decisions they make about children are always open to question and challenge because there is no strong, science-based body of knowledge to legitimize such decisions. Clinical decisions made by doctors may not be grounded in science or scientific evidence, yet because the medical enterprise is perceived by the public to be more strongly grounded in science than it is, the decisions are legitimized as if they *were* firmly grounded in science.

Nevertheless, rising public expectations of both professions have given birth to demands for greater accountability, which in turn have fuelled more specific demands, for instance in terms of what diagnostic procedures or specific treatments patients want from their doctor, or in terms of the curriculum content or levels of achievement that parents demand of teachers for their children. And in many countries politicians have sided with the consumers rather than the professionals. A significant knowledge gap between doctors and their patients remains, of course, but this is to some degree eroded by the public interest in medicine, an appetite fed by newspaper and magazine articles promoting health and by television series about life in hospitals which diffuse knowledge of medical terminology and practices. Though much doctor-doctor talk seems initially incomprehensible (as in ER, the popular American television series), if the gap is to be closed it is seen to be the responsibility of lay-people to learn the technical language for themselves, as it is thought to be right and proper that doctors should talk *scientifically*. And in extreme cases, such as the Aids crisis in the United States, activists will master the medical knowledge-base to a degree that disconcerts and destabilizes the medical establishment (Epstein, 1996). The knowledge gap between teachers and lay people is relatively small, and where there is a gap to be closed, it is seen to be the teachers' responsibility to do so, for they are held to have a duty not to use "jargon" when everything they do as teachers could so easily be explained in less obfuscatory terms.

Professional training and the knowledge-base

The nature of the knowledge-base for both teachers and doctors is affected by the nature of their basic or initial training. Within medicine there is a split between physicians and surgeons. Physicians have always set store on their expertise being grounded intellectually in higher education and thus see the university as a natural seat of professional learning. The origins of surgeons' training lie in the apprenticeship mode of the barber-surgeons. Today, both types of doctor have a strong academic element to the knowledge-base but see its acquisition as requiring practical apprenticeship under an experienced and more expert practitioner. Nowhere is this better exemplified that in the life and influence of Sir William Osler, who made a major contribution to the nurturing of scientific medicine, yet combined this with a passionate belief that medicine could only be fully learnt on the wards with patients. As a gifted teacher he placed emphasis on

> (...) full and prolonged clinical instruction, and on the importance of bringing the student and the patient into close contact, not through the cloudy knowledge of the amphitheatre, but by means of accurate, critical knowledge of the wards (...).

and insisted that

> I desire no other epitaph (...) than the statement that I taught medical students on the wards, as I regard this as by far the most useful and important work I have been called upon to do (Osler, 1904).

Believing thus that the main purpose of the medical school was to train effective doctors, Osler fully recognized the fundamental tension in the professional knowledge-base when he observed that

> (...) the greatest difficulty in life is to make knowledge effective, to convert it into practical wisdom (quoted in Bryan, 1997).

The tension in medical education between formal training and apprenticeship persists to this day (Vang, 1994; Starr, 1982). In the United Kingdom, doctors who wished to train as a hospital specialist used to spend between ten and fourteen years after registration under the supervision of a consultant (or attending, in US parlance) before they were qualified to become a consultant. The reforms to bring the period of such training into line with the European Union now require that the training period be reduced by half. Though there is a formal element to this training, in examinations set by the relevant Medical College, much of the training provided by the consultant is informal, practical on-the-job training in apprenticeship mode. The response of the consultants to the reduction in the post-graduate training period was to demand more time for formal teaching, whereas the juniors asked for a higher quality on-the-job training.

I have distinguished two forms of this apprenticeship, apprenticeship-by-osmosis and apprenticeship-by-coaching (Hargreaves *et al.*, 1997*a*; 1997*b*). In apprenticeship-by-osmosis the consultant leaves the responsibility for learning almost entirely to the junior doctor, who can passively absorb what can be gleaned from watching the consultant at work and who can extract explicit teaching from the consultant only by taking the initiative to do so by diplomatic means. In apprenticeship-by-coaching, the consultant accepts responsibility both for teaching and for helping the junior to assume greater responsibility for learning. Apprenticeship-by-osmosis has been a traditional pattern of postgraduate medical training, but is being replaced by apprenticeship-by-coaching.

Many doctors are ambivalent about their concept of apprenticeship and its role in the acquisition of the medical knowledge-base. They feel the idea is valuable because becoming a skilled medical practitioner requires practical, hands-on experience under the supervision of an experienced colleague, and cannot be learnt from text-books. At the same time they are conscious that the element of osmosis leaves too much to chance, which is what happened in earlier forms of initial teacher training. Retention of some form of apprenticeship model is strongly supported by theories of situated learning (Lave and Wenger, 1991), in which learning is no longer seen as something which takes place only in the mind, structurally independent of the context in which it takes place. Rather, the context and situation and the mental learning interpenetrate one another. Learning to be an effective medical practitioner is learning to *do* something, to perform in a given way, not to be able merely to talk about it. Learning, in other words, is always situated, and is most effectively acquired in the same setting as that where the learning is to be later exercised or applied.

To become a professional is, on this view, a process of becoming a full member of a *community of practice*. The novice, or junior doctor, enters the community of medical practice by participating in a peripheral way, not only by doing simple, delegated tasks and the "scut" work but also by *assisting*, or making a partial and limited contribution to the work as a partner of the full member of the community of practice, namely the consultant. Becoming a full member of a professional community is a matter both of acquiring knowledge and skills and of acquiring a relevant identity; and both professional skill and professional identity are progressively acquired by participation that becomes decreasingly peripheral over time. Novices learn not merely to talk *about* the practice of their profession, but *within* it. Learning is not merely a condition for membership of the community of doctors (or teachers), but is itself an evolving form of membership.

Such learning-through-contextualized-practice is effective in part because this is the more natural way of acquiring the *tacit* knowledge (Polanyi, 1966) that is an inherent feature of complex skills. We know more than we can say. Some knowledge is not easily expressed in words, and so is difficult to talk about (as in a lecture) or write about (as in a text-book) or to communicate from "master" to "apprentice". Some learning is more readily achieved if apprentices watch the master at work in a demonstration or modelling of the skill concerned and then try it out under guided supervision for themselves. Much of what professionals call "professional judgement" draws heavily on such tacit knowledge, as when a physician rapidly diagnoses a rare condition or selects a management option that is highly appropriate to the specific condition and circumstances of an individual patient – but in both cases may find it difficult to say how the conclusion or decision was reached. (The same applies to experienced teachers, who do not find it easy to explain how they can successfully anticipate pupil problems or can select an effective way of helping a pupil from a wide range of options in a way that seems highly opaque to the novice.) Consultants' insistence that "clinical judgement" cannot be taught, but only acquired through experience, confirms the thesis that an adequate professional training requires apprenticeship through peripheral participation in a community of practice.

The theory of situated learning thus validates and legitimizes the traditional commitment of doctors to notions of apprenticeship. Learning in the lecture room is not context-free learning, but learning-in-the-lecture-room. The same can be said for private study. In both cases there will be problems in transposing context-of-study knowledge into a context-of-use practice. Better training for junior doctors would often be more readily achieved by more effective coaching within an on-the-job apprenticeship mode than by extra formal teaching. In the United Kingdom and in the United States – but not in Germany – craft apprenticeships declined rapidly in the twentieth century (Roberts, 1993; OECD, 1994; Lane, 1996). In the United Kingdom they have recently been revived on a small scale, which is a welcome recognition that one of the oldest and most tested forms of transmitting a knowledge-base might have some advantages over the now ubiquitous off-the-job formal training that has come to be almost synonymous with education (Hasluck *et al.*, 1997; Fuller and Unwin, 1998).

In the education and training of teachers, by striking contrast to that of engineers and doctors, the concept of apprenticeship has often been openly treated as a term of abuse for a form of teacher training which is held to be seriously and irremediably defective. Teacher training in the United Kingdom has also been reformed by government fiat. Until recently, graduates completed a year of full-time initial teacher training, two thirds of which was devoted to study in the university and one third of which was spent in schools under the supervision of a practising teacher (the "teaching practice"). In 1992 the government reversed these allocations, to the consternation of university-based teacher trainers, distressed at being instructed to transfer a portion of student teacher fees to the schools in recompense for the longer period of school-based supervision.

Prior to these reforms there was rarely a job description for the practising teachers who supervised the teaching practice, nor was any training provided for them. School-based supervisors have now been given a new name – mentors – and many books now advise on how the role should be carried out. Senior doctors with responsibilities for training junior doctors could learn much from the development of mentoring in teacher education – and they could offer something in return to the conception of the mentor. For the model of mentoring, and of how trainee teachers learn, is not, as one might expect, based upon the theories of situated learning described above. Rather, the dominant model is that of *the reflective practitioner* (Schön, 1983; 1987). Though there are many reasons to explain the appeal of this concept to teacher educators, an important one is that it legitimizes the critical scrutiny, rather than transmission, of existing professional practice. In medical postgraduate training, the supervisor of the trainee is an experienced practitioner whose role is to induct the novice into the profession and to pass on one's own knowledge and skills. In postgraduate teacher training, the university-based tutor is not a current practitioner but an academic who has sometimes regarded the mentors as a threat insofar as they may transmit obsolescent or ineffective conventional practices to trainees. In such circumstances the university-based academic is suspicious of apprenticeship and the associated notion that the mentor should offer the trainee peripheral participation in a community of (potentially dangerous or unworthy) practice. Instead the trainee should be inoculated against catching the diseases of conventional practice, and this is most easily achieved if both university-based tutor and school-based mentor adopt the reflective practitioner model which requires the trainee constantly to challenge the assumptions behind existing professional practice and to consider alternatives to them. The weakness of this position is obviously that the trainee is being expected to become critical of professional practice before much of the basic knowledge and skill has been acquired.

Research, knowledge production and the professional knowledge-base

Practising teachers who serve as mentors for trainee teachers are usually not actively engaged in educational research and development. Educational research and knowledge production in the United Kingdom is funded from various sources – national and local government, research councils, charities, business – but most of it is channelled though the universities, where academics design and execute the research. Only rarely do practising teachers play a part in the design of research programmes or receive funding to carry it out.

In medicine, by contrast, much research and knowledge production is carried out by practising doctors, rather than full-time researchers no longer working with patients. In consequence, the research agenda is heavily influenced by front-line practitioner concerns, and trainees are supervised by consultant practitioners who both carry out the research and apply the results to their practice. In teacher training, the school-based mentors are very unlikely to be active researchers or applying outcomes to their practice. They provide for trainee teachers a very different model of how new knowledge is generated, disseminated and then applied to improve practice. It is in the university, rather than in the school, that the model for research is provided, but most trainee teachers will spend their lives in schools, not the university. The substantial overlap in medicine between hospital practitioners and researchers socializes young doctors to attitudes and practices that are very different from those in education where there is a sharp split between the two roles.

Among educational researchers there is a deep dispute about why educational research has relatively little impact on changing school teachers' professional practices. It is argued that the social sciences are not well placed to generate the kind of research styles or research outcomes that can directly guide professional practice and that in any event the variables affecting professional practice are much more complicated in school classrooms than in medical consulting rooms. This denial that research is likely to have much direct impact on practice thus sustains the so-called "enlightenment" view of educational research, in which the function of research is to change the climate of opinion and understanding rather than to affect the immediate concerns of policy or practice. Though obviously containing some partial truth, this view of research is easily interpreted as a discouragement of applied research which seeks to have some short-term impact on policy or practice. It also assumes that the ideas emanating from the research community are generally beneficent as they penetrate the practitioner community, whereas some of these ideas, in the United Kingdom those of Bernstein and Piaget in particular, have entered practising teachers' minds in a highly distorted form during their academic initial training, and sometimes had very negative effects on practice.

Evidence-based practice and the professional knowledge-base

The dangers of over-emphasis on the enlightenment thesis of the impact of research are particularly apparent when educational researchers are confronted with the rapid growth of *evidence-based medicine* (or EBM for short). This movement begins from a recognition that much current clinical practice is not grounded in firm evidence or a body of scientific knowledge, or is not so grounded to the extent that it could and should be.

> The fact that medical treatment is not invariably followed by clinical improvement is not one that those interested in medical quality – be they patients or doctors – can ignore (…). It is as if once a treatment has been given then medical obligation is at an end. Or, to put it another way, the outcome of treatment seems sometimes to be less important than its actuation (…). Whatever the reason, it is highly likely that a large proportion of treatments, not to say investigations and referrals, are no more than a face-saving disguise for medical impotence (Pickering, 1996).

> Many idealistic students enter medicine in the belief that they will become "rescuers": active agents who will save the sick from untimely death. The mundane truth – most patients improve without treatment – comes later, and, for some rescuers, this humbling insight never arrives. All too often, an inflated view of medicine's prowess has led to action that is both unfair and harmful (Silverman, 1997).

> Most physicians can remember the day when, armed with a degree, a mission, and confidence, they could set forth to heal the sick (…). Each physician was free, trusted and left alone to determine what was in the best interests of the patient (…). All of that is changing (…) one of the basic assumptions underlying the practice of medicine is being challenged. This assumption concerns the intellectual foundation of medical care. Simply put, the assumption is that whatever a physician decides is, by definition, correct. The challenge says that while many decisions no doubt are correct, many are not, and elaborate mechanisms are needed to determine which are not (Eddy, 1990).

Nor is this merely a matter of minority, self-critical medical opinion: hard evidence derives from studies of medical practice variation.

> Similar patients treated for the same diagnosis have hugely variable outcomes depending on their clinician, hospital and geographic location. This phenomenon is unnerving and largely unexplained (Eve and Hodgkin, 1997).

> Every clinician knows that there is indefensible diversity in the use of diagnostic methods and therapies and that there is unacceptable variation in the quality and treatment delivered by different clinical teams (Peckham, 1991).

Of course, the training of doctors probably leads them to exaggerate the significance of therapeutic intervention in terms of a nation's health and so they regard the exposure of their practice (and related knowledge-base) as not grounded in evidence as an embarrassment. And the same applies to the realisation that common surgical operations of the past, such as tonsillectomy, were fads and fashions performed on many patients without scientific or medical warrant. Nevertheless EBM is a somewhat controversial concept. To some, it is what doctors have always done, or should have been doing, all along; to others, it is a threat in that it appears to reduce the physician's clinical discretion or judgement and puts far too much faith in the conclusions drawn by researchers or reviewers of research. Its leading British advocates express the intention simply.

> It's about integrating individual clinical expertise and the best available evidence from systematic research (…). By *individual clinical expertise* we mean the proficiency and judgment that individual clinicians acquire through clinical experience and clinical practice. Increased expertise is reflected in many ways, but especially in more effective and efficient diagnosis and in the more thoughtful identification and compassionate use of individual patients' predicaments, rights and preferences in making clinical decisions about their care. By *best available external clinical evidence* we mean clinically relevant research (…) especially from patient-centred clinical research into the accuracy and precision of diagnostic tests (…) and the efficiency and safety of therapeutic, rehabilitative and preventive regiments(…). Good doctors use both individual clinical expertise and the best available evidence, and neither alone is enough. Without clinical expertise, practice risks becoming tyrannized by evidence (…). Without current best evidence, practice risks becoming rapidly out of date (Sackett *et al.*, 1996, italics added).

There is nothing here to endorse fear in the teaching community that evidence-based practice entails researchers providing practitioners with mechanistic and simplistic solutions to complex problems, nor does it endorse an "enlightenment" view of research as being restricted to some generalised, indirect enlightenment of practitioners and their understandings. Between these extremes, EBM offers a practical middle way which requires that *i*) researchers undertake the appropriate patient-centred research *ii*) which is collated and mediated to the clinician when needed and *iii*) is then taken into account by the clinician as part of the professional judgement in making diagnostic or therapeutic decisions about the individual patient with distinctive characteristics in distinctive personal and social circumstances.

It is the second of these elements, the collation and dissemination of the research findings, which is the most difficult to achieve. Most doctors subscribe to professional journals – the *British Medical Journal* and the *New England Journal of Medicine* are world famous – which enjoy some success in mediating research evidence to strengthen the knowledge-base of practitioners. (There are no equivalents for teachers.) But journals, however good, are not enough. One study (McColl *et al.*, 1998) has shown that most general medical practitioners are supportive of EBM and believe it contributes to better patient care, but experience problems in finding easy access to, and time to consult, the research or research reviews. Cheaper and more widely available information and communication technologies will soon support better dissemination at reduced costs.

An evidence-based approach in education has as much promise for improvement as it has in medicine, but costs are involved here too. As things stand, there is too little research of the kind that is relevant to practising teachers and policy makers, largely because so much research is supply-led rather than demand-led. Action needs to be taken to focus research more strongly on classroom pedagogy; and teachers and policy makers need to play a stronger role in shaping the agenda and priorities for education research. There will also be a need to foster, within a more focused educational research, experiments of various kinds, and especially randomized controlled trials, which have become the gold standard in medicine (Maynard and Chalmers, 1997) but are exceedingly rare in education. Only from studies such as those conducted in medicine can a knowledge-base be generated that will save teacher time and energy by identifying interventions that are pointless or even harmful to pupils.

Evidence-based teaching and teacher-researchers

In some respects teachers and physicians face similar problems.

> [P]hysicians must make decisions about phenomenally complex problems, under very difficult circumstances, with very little support. They are in the impossible position of not knowing the outcomes of different actions, but having to act anyway. No one is questioning the sincerity, honesty or diligence of physicians (…) [but] physicians must have solid information about the consequences of different choices and must be able to process the information accurately. Currently we lack both the information required for decision making and the skills needed to process the information (…). The solution is (…) to improve the capacity of physicians to make better decisions (…) and we must build processes that support, not dictate, decisions (Eddy, 1990).

It is on such premisses that evidence-based medicine is built. Of the changes required to establish, or strengthen, evidence-based teaching, supporting more practising teachers in schools as researchers is among the most critical. Personal involvement in research at some stage in one's career is a key sensitizer to the value of research findings and, as in teaching hospitals, a vital element in the creation of a culture in which research is valued.

There are three main impediments to the creation of more teacher-researchers. The first is the lack of funding. Many teachers are willing to do research, and to do so in partnership with universities, but they lack the resources to pay for the substitute or additional teachers needed to release them from classroom duties. This can only be achieved by diverting to schools, and the school-based research consortia now being established in the United Kingdom, some of the research funding now in the hands of universities.

The second impediment is the failure to re-shape the profession so that teacher work in classrooms is set at a higher professional level. Doctors delegate much of their work – the minor ailments that are easy to treat, or other specialised tasks – to trainee doctors, nurses or para-medical staff. By delegating more to assistants, teachers could reserve to themselves the important educational problems that require high level skills, experience and professional judgement. This would provide space for, and the incentive to pursue, research into more effective professional practice to strengthen teachers' knowledge-base.

That many teachers lack the confidence to engage in research is a third impediment. There is now a significant pool of potential researchers among teachers, namely those who have undertaken a higher degree in education, which often includes research training and some practical research experience. With more support such teachers could continue with some research and quickly establish the principle of the teacher-researcher. Knowledge monopolies are a key source of professional power, and as in the United Kingdom the responsibility for initial teacher training has been progressively transferred to teachers in schools, the knowledge-power-base of academic teacher trainers increasingly lies in their monopoly over knowledge of how to do research. The extent to which they will allow this knowledge to be diffused to the whole profession is unclear.

Science, art and professional tinkering

The creation among teachers of more positive attitudes towards evidence-based teaching would involve changes in teachers' psychology and their professional culture. Both doctors and teachers are conscious of the artistic elements in their professional practice. Teachers often take pride in the fact that their knowledge is intensely personal, carved slowly over the years out of private (not collective) experience. Although this is less evident among doctors because of the stronger scientific base to their knowledge, they too constantly emphasize the artistic elements in their diagnostic and therapeutic decisions, relating what they know from science to the unique circumstances of the patient at hand. "Medicine", said the American physician Oliver Wendell Holmes (1871), "is the most difficult of sciences and the most laborious of arts", and this was echoed by Sir William Osler's (1904) assertion that "The practice of medicine is an art based on science (...). For perdition inevitably awaits the mind of the practitioner (...) who has never grasped clearly the relations of science to his art, and who knows nothing, and perhaps cares less, for the limitations of either". In the same spirit, the British physician, Lord Platt (1972), defined diagnostic skill as being one "more closely allied to the skill of a connoisseur examining a picture or an old violin than it is to what we normally think of as science".

Insisting that professional practice has artistic features shores up professional autonomy, which is fiercely defended. For doctors, the right to independent clinical judgment is needed to protect them against a view that medicine's scientific knowledge-base can be applied in any narrowly technical or standardized way. For teachers, the right to work in one's classroom according to one's own lights is held to protect them against educational fashions or political incursions into pedagogy. Teachers might, however, be willing to sacrifice some of their autonomy for a better knowledge-base through evidence about "what works" in education. This might not simply make them more effective, but paradoxically it might increase their autonomy by protecting them against politicians telling them what to do, especially when ministers have no sound evidence for their prescriptions, their preferences having no greater warrant than the fads and fancies that flourish among teachers in the guise of professional knowledge. At the same time, if a treatment, especially a cost-effective one, has been shown to work, politicians might argue that all practitioners should adopt the treatment and thus attempt to over-ride professional autonomy.

Whatever science might contribute to their practice, both doctors and teachers have to exercise considerable professional judgement in making their higher-level decisions; they have to "read" both client and context and be prepared to adapt their treatment until they find something that "works" with the client, whether patient or pupil. In short, and as discussed in Chapter 3, they learn to *tinker*, searching pragmatically for acceptable solutions to problems their clients present. In other words, all professionals have to develop a craft aspect to their practice, whereby through accumulated practical experience they add to their formal knowledge-base mental schemata that provide typical solutions to typical problems presented by typical clients (Schutz, 1964) – whether it be "a difficult child in the playground who must be watched if trouble is not to start" or "an unco-operative patient in clinic who needs to be cajoled into accepting the procedure". These schemata become tacit or intuitive, until they do not work as expected, at which point the professional chooses to tinker, drawing upon the whole of the knowledge-base, in a novel way to discover something that *does* work. This tinkering is a very small scale, spontaneous and mundane way of solving minor, everyday problems of a professional's life. But sometimes this tinkering is on a grander and more formal scale, a more carefully considered and radical way of dealing with a persistent problem: it then becomes research for knowledge creation.

Tinkering is, in effect, an uncontrolled experiment and in this sense every treatment of a patient by a doctor and every treatment of a pupil by a teacher is in the nature of an experiment. If, as a consequence of tinkering, an innovative practice is successful, *i*) it is usually incorporated by the individual practitioner into an enhanced *personal* knowledge-base. To become *ii*) part of the *collective* professional knowledge-base, it has to be disseminated among colleagues and accepted by them as "good practice". It *iii*) enters the collective knowledge-base in an evidence-based form only when it is subjected to research and accepted as a verified professional practice which works. Eventually, it *iv*) enters the formal corpus of professional knowledge, especially when it can be related to formal theory and academic knowledge, and then slides back into the official professional knowledge that is transmitted to novices in their initial training.

Both doctors and teachers tinker and regularly go through steps *i*) and *ii*) with novel practices. Doctors are ahead in learning that steps *iii*) and *iv*) are an essential path to better professional practice with verifiably better outcomes for clients. Teachers share a tinkering psychology with doctors. How can they build on this foundation to create the knowledge to enrich their knowledge-base in a practitioner-led, research-based way?

Professional knowledge: from creation to institutionalization

In the short term social science is incapable of providing the greatly improved knowledge-base that teachers need. There are some promising areas, certainly, such as the neuro-sciences, but these are largely at the "basic" rather than the "applied" level. Much of the relevant basic research, in the neurosciences and cognitive sciences, is likely to be conducted in university faculties other than education, which creates problems in the dissemination of such new knowledge into the university departments that bear responsibility for initial teacher training and the continuing professional development of teachers. While the medical school and teaching hospital have often served as the bridge between the basic sciences and clinical practice, university schools of education often have tenuous links with cognate departments. Even if cognitive psychology does, over coming decades, generate a potentially powerful knowledge-base for teachers, there is no adequate system for mediating such knowledge into the teaching profession.

In the short term we must look elsewhere for a means of strengthening teachers' knowledge-base, namely to the development of an evidence-based approach to the practice of teaching. More and better designed studies of "what works" in schools and classrooms could provide a knowledge-base, because such research can be done without necessarily finding a theoretical base for interpreting the results. In other words, the science to support education would be in terms of research *methodology derived from science*, not a substantive body of *scientific theory* as such. Indeed, if we knew much more, in relation to teachers and students in schools and classrooms, about what worked for whom under what circumstances and with what effects, this knowledge would be of real practical value to teachers, who should respond well to the notion of evidence-based teaching. At the same time educationists in universities should develop theories around such empirical findings. In medicine, too, it is not unknown for practice to be in advance of theory – anaesthesiology being a good example. In short, whereas in medicine the full-blown development of an evidence-based approach *followed* the establishment of a scientific infra-structure to its knowledge-base, in the case of education this might be reversed, with the establishment of an evidence-based approach *preceding* and actively promoting a social scientific infra-structure.

Who, then, would undertake the research on "what works?" to generate evidence-based teaching and to do so in a way that contributes more rapidly and coherently than in the past to the enhancement of teacher and school effectiveness? Some university-based researchers already contribute to this, but the majority prefer to conduct research on topics of their own choice in their own style. Without some incentive to change, I see no reason why higher education should be

> (…) prepared to extend its role from that of creator and transmitter of generalizable knowledge to that of enhancing the knowledge creation capacities of individuals and professional communities (Eraut, 1994).

And that is surely what is now needed. There is massive, innovative activity and potential locked up in the "tinkering" of teachers in their classrooms. We need to investigate and codify when and why this innovative activity does (or does not) work.

There is evidence in the United Kingdom that researchers will change their agenda when research funding is tied to particular themes, so more funding must be directed towards achieving the specific objective of enhancing the creation and dissemination of better professional knowledge and practice. One controversial move in this direction, initiated by the Teacher Training Agency in England, has been to channel research funding directly to schools, which then, in a reversal of the conventional mode, seek a partner university to assist them in carrying out the research. This could be substantially increased. Maintaining a strong tie between university-based teacher education and professional R&D has advantages.

> Cognitive commonality, however minimal, is indispensable if professionals are to coalesce into an effective group. Codification of knowledge (…) depersonalizes the ideas held about professional practice and its products. It sets up a transcendent cognitive and normative framework within which, ideally, differences in the interpretation of practice (…) can be reconciled. The formalization of the cognitive base of a profession has a powerful effect on professional unification because it allows a deeper and more thorough standardization in the production of producers than would otherwise be possible (…). Training and research increasingly depend on the same institutional structure (…). Thus in its modern sense, profession appears to be a structure which links the production of knowledge to its application in a market of services; the training institutions are the empirical arena in which the linkage is effected (Larson, 1977).

Combining the production (or creation) of knowledge with the production (or training) of the professional has over time tended to become more and more located in the university (Freidson, 1986). For this reason high status continuing professional development for experienced teachers has also been located within universities. It is no accident that declining faith in the capacity of universities to generate the knowledge-base for teachers coincides with scepticism that improving the knowledge-base of teachers is best achieved by attendance at courses outside the school. Both initial teacher training and continuing professional development are now more frequently located in the school and directed towards collective and sustained innovation and change. If the two forms of production are to be bound together, then some of the knowledge production or research must also be transferred to schools. In other words, the dislocation of knowledge production from knowledge application must be brought to an end wherever possible. Only thus can a better knowledge-base for teachers be generated, one which, because it focuses on "what works", will contribute to the current political imperative of more effective teachers in more effective schools.

More and better R&D, with the specific aim of promoting evidence-based teaching, done in partnership, provides opportunities for larger-scale, multi-site experiment undertaken by teacher-researchers working on a common topic but co-ordinated by collaborating academics. Some structural reform would help. R&D in the field of public health and health services in the United Kingdom was strengthened by the introduction of regional R&D centres with a director and support staff (Peckham, 1991; Black, 1997) and regional centres for educational R&D (Hargreaves, 1998) could provide the infrastructure for parallel developments in education.

Schools as training centres *and* research centres increasingly makes sense in that it is in both training and innovation that the *tacit* knowledge of the effective practitioner has to be made more explicit and this is a critical element in successful knowledge creation (Nonaka and Takeuchi, 1995) and transfer. This tacit knowledge of the experienced practitioner, which is so rarely drawn upon by professional researchers, is at its most refined in the middle managers of secondary schools – those who have long experience of teaching but have not moved into full managerial positions with a different knowledge-base. It is they who become the senior mentors for trainee teachers and it is they who have often taken a higher degree in education and thus obtained some experience of educational research; it is they who are potentially what Nonaka and Takeuchi call *knowledge engineers*; it is they who should be leaders of their peers coming together to share experiences, to experiment together and, when success is achieved, to engage in lateral dissemination through their networks.

All this would entail a significant re-conceptualisation of what is seen as the dissemination process, which has conventionally been portrayed as a linear, centre-to-periphery process from research in universities out to teachers in schools. Much innovation in education, unless it is mandated, does not get beyond the diffusion phase, because insufficient attention is paid to the deep problems associated with adoption, implementation and institutionalization processes in linear models (see Chapter 2). As long as we continue to believe that the most effective way of improving professional practices is "outside in", that is, produced from outside schools and then disseminated by reformers into them, then the successful adoption, implementation and institutionalization of new practices will continue to be a relatively rare phenomenon and policy makers will be frustrated by the failure of many reforms to endure and to displace poor practices. People are motivated to disseminate knowledge that they have themselves created; and there are natural, but under-used, channels for easy dissemination. If schools were more fully developed as centres of initial teacher training and research, with experienced knowledge engineers on the staff, they might "(…) actually create new knowledge and information, from the inside out, in order to redefine both problems and solutions and, in the process, to recreate their environment (Nonaka and Takeuchi, 1995)".

Schools as knowledge-producing and knowledge-mediating institutions are in their infancy, but they may well be one important route to the continuous improvement and enhanced effectiveness of schools now being demanded by politicians in many countries.

Without question doctors have been much better than teachers at advancing their professional effectiveness by combining research with practice in the interests of knowledge production. At general practitioner level, however, group practices are often too small to be powerful knowledge-creating organizations. At hospital level, much of the innovative capacity is tightly locked within, and restricted to, each specialist department. Whilst new ideas and practices can be reasonably well disseminated through specialist journals and specialist medical associations, it is exceptionally difficult to diffuse evidence-based new practices *between* departments and specialties or within the *same* hospital. In this regard schools have a considerable advantage over both group practices and hospitals (though perhaps not health centres), for there is now a stronger focus on cross-departmental interaction and joint learning. In the United Kingdom, teachers speak of "whole-school policies" and "whole-school professional development" in a way that simply cannot be found in most hospitals. Schools are closer to becoming "learning organizations" than are hospitals.

A generic model of the professional knowledge-base

The above comparative analysis may, now set within the theoretical context of a generic model of the knowledge-base, be summarized as follows. Whereas the *content* of the knowledge-bases of doctors and teachers are very different indeed, the *structures* of the knowledge-bases have both similarities and dissimilarities.

The main similarity is in the structural *components* of the knowledge-base, as illustrated in the three-dimensional Figure 1. In the central, horizontal axis, four analytically distinct types of knowledge are represented:

– D*eclarative knowledge* (DEC-K), or "knowing that", which is often in a propositional and codified form.

– S*cientific knowledge* (SC-K), which is a distinctive form of codified knowledge.

– P*rocedural knowledge* (PROC-K), or "knowing how".

– P*ersonal knowledge* (PERS-K), in which through experience, including trial and error and other forms of learning-by-doing, the individual builds up and seeks to integrate a professional knowledge-base and develop expert professional judgement.

The first two kinds of knowledge are formal and largely explicit, with relatively low levels of tacitness. The latter two kinds of knowledge are rich in what is tacit. Each type of knowledge interacts with the other three types.

A second similarity lies in some shared *features* at the core of the knowledge-base and its four types of knowledge, especially the concepts of the diagnosis and treatment of clients and their problems, including how diagnoses and treatments are set with a dictionary of professionally legitimate problems (classification) and what counts as evidence for them (colligation). The acquisition of systems of classification and colligation is a key feature of professional training and socialization. Classification and colligation exemplify the dynamic interaction of the four types of knowledge.

Three dissimilarities are evident. At the pole in the upper half of Figure 1, knowledge is the unique possession of the *individual* or idiosyncratic, whereas at the opposite pole, knowledge is *social* or a collective possession of the profession. The first dissimilarity between teachers and doctors concerns the different *evolutionary paths* that have been taken by the two professions. The role of science in medicine has drawn the knowledge-base towards the social pole, whereas the lack of the science among teachers has drawn their knowledge-base towards the individual pole.

The second dissimilarity is in the form of training for the profession. Among doctors the apprenticeship model has remained strong, since both the explicit *and* the tacit aspects of the knowledge-base require effective social transmission from expert to novice. Among teachers there has been a movement away from apprenticeship towards (a version of) the "reflective practitioner" so that the social transmission of the knowledge-base, both explicit and tacit, from expert to novice is neglected and the professional socialization is further drawn towards the individual pole.

The third dissimilarity is in the approach to research and development. Again, doctors remain in the lower half of the figure, where the development of evidence-based medicine is concerned with the sharing of validated professional knowledge. Teachers, locked in the upper part of the model, engage in talk about "good practice" but have no agreed means of validating or sharing their professional practices.

Figure 1

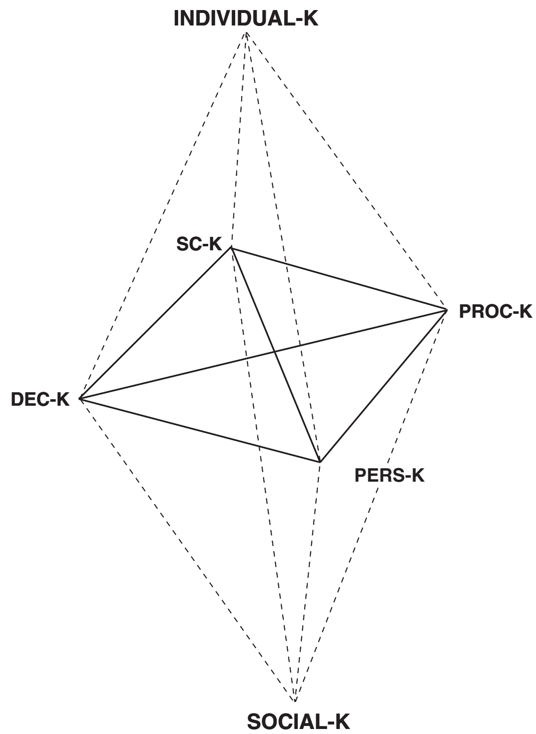


Figure 2

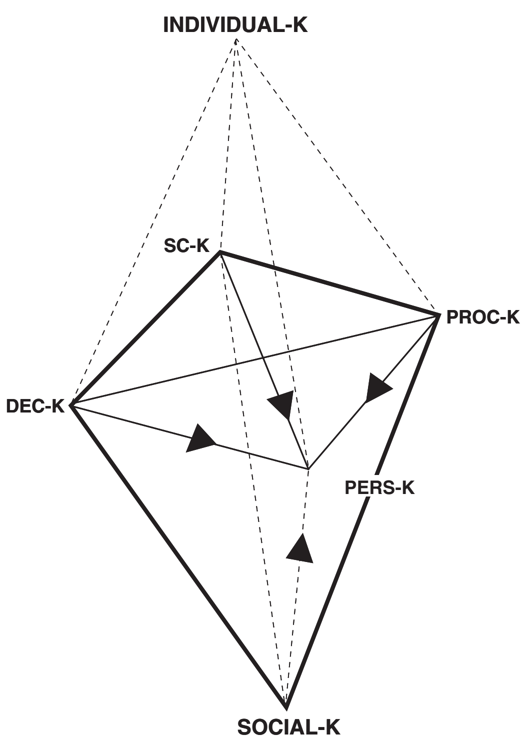
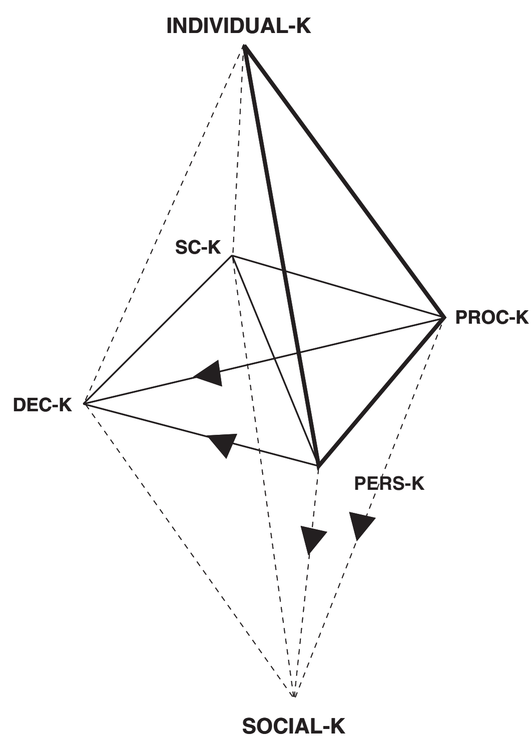


Figure 3



There is also, however, a third similarity, which is the concept of *tinkering*. In both professions this is strongly linked to personal knowledge. For doctors, it is a step not only towards better professional practice for the individual but also potentially a contribution to evidence-based and socially shared professional knowledge. For teachers, tinkering is largely interpreted as a means of developing better personal knowledge for the individual, but may be the key to the emergence of a more valid and even scientific and socially shared knowledge-base, to fill the gap left by failures in social science.

Figures 2 and 3 provide a graphical illustration of the contrasting strengths of the components of the two knowledge-bases (thicker lines). For doctors, the internal dynamic of the forces in the knowledge-base drive towards the more secure construction of the personal knowledge of each physician or surgeon, all forms of knowledge leading over time to the development of expert professional judgement. In the case of the teachers' knowledge-base, the external pressure on teachers, teacher trainers and educational researchers in many countries to improve the quality of teaching as a means of raising educational standards is now changing the internal dynamic of what has hitherto been the dominant model towards the development of a public or shared language for professional practice, since this is a prerequisite for more effective means of sharing and disseminating knowledge of professional practice that has been made explicit and subject to public validation. It remains an open question whether such changes in the teachers' knowledge-base will also include a scientific element of some kind, to which the declarative, procedural and personal components are then linked.

Conclusion

These potential changes in the knowledge-base of teachers can be understood within a wider theoretical framework for understanding knowledge production. Seen in this light, the educational reforms in the United Kingdom, such as school-based initial teacher training, school-based research, evidence-based professional practice and a renewed focus on teachers' classroom effectiveness, can be interpreted as part of the deeper social changes by which many kinds of knowledge production are moving from what Gibbons *et al.* (1994) call Mode 1 – pure, disciplinary, homogeneous, expert-led, supply-driven, hierarchical, peer-reviewed, university-based – towards Mode 2 – applied, problem-focused, trans-disciplinary, heterogeneous, hybrid, demand-driven, entrepreneurial, accountability-tested, embedded in networks. Across many spheres of knowledge production there is said to be a general movement away from Mode 1 towards Mode 2; education is unlikely to remain exempt from these changes. My concluding hypothesis is that in the United Kingdom this rapidly growing movement within education towards Mode 2 will soon put United Kingdom education at the leading edge of educational knowledge production. Since the universities are the institutions where the transition from Mode 1 to Mode 2 can be particularly painful, the bitter opposition of the university-based teacher trainers to recent reforms may simply confirm that this process is indeed under way, probably irreversibly. It will need courage for university-based educationists to adapt to the new role they have to play if Mode 2 educational knowledge production is to be successful.

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CHARACTERISING THE KNOWLEDGE BASE: AVAILABLE AND MISSING INDICATORS

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Introduction

This report aims to develop an analytical framework and a set of indicators for casting light on the transformation of knowledge bases in various economic sectors. This is an important aspect of an OECD/CERI project on the production, mediation and use of knowledge in different sectors. Knowledge processes in the engineering, health, ICT and education sectors have been examined closely at forums in Tokyo, in Paris and at Stanford University. The fourth forum, organised with the US National Science Foundation, Washington, DC, focuses on the measurement of knowledge processes and on the transformation of knowledge bases in both the public and private sectors.

At first glance, it would seem that there has been enough research, either on the indicators themselves or on broader qualitative analysis, to gain an understanding of the *essential parameters* needed to characterise the transformation of a knowledge base at the sector level.

It is, however, very difficult to develop a set of measurements for improving our grasp of the logical aspects of the knowledge base in a given sector and our understanding of how it is transformed. The standard approach for developing indicators consists of producing a series of *descriptors*, from which *essential parameters* are generated, and which in turn are used to produce *indicators*.

Descriptors Essential parameters Indicators Data

The first section describes some major problems for measuring the transformation of a knowledge base. The second section examines the leading descriptors of a knowledge base in order to identify the parameters and indicators. It draws on examples taken from the education, health care and engineering sectors.

Problems and review of methods

Problems related to the diversity of situations

First, a presentation of descriptors presupposes that the constituent parts, processes and performance of the knowledge base can be known. However, to create a framework applicable to sectors which are different, even extremely different as in the present instance, is a very difficult task. The descriptors must be sufficiently generic in order to cover all sectors; yet they must closely duplicate the "real world" in order to reflect the specific nature of those sectors. The conflict is generally resolved by adding descriptors, some of which will be omitted in certain situations. Consequently, the largest possible set of descriptors is assembled in order to anticipate all potential problems, so that no additions are required, at least for quite some time, but certain descriptors are not used for certain sectors.

Unfortunately, the diversity of sectoral patterns is probably too great to generate indicators for grasping the knowledge base. It is therefore necessary to structure this diversity to some degree to make it more tractable. Two parameters can be considered.

The first is provided by Murnane and Nelson (1984), who describe two worlds. In one, "Separate R&D activity standing at 'some distance' from production and operated by specialists is the basic source of new knowledge; R&D creates new products or processes that can be described accurately with blueprints or sets of instructions and which, therefore, can be replicated and diffused from place to place" (p. 366). Although the notion of the "distance" between R&D and production is extremely variable and the degree of tacitness of the knowledge base may be high, the direct usefulness of R&D and the importance of codified knowledge appear to be the key determinants of the dynamics of the knowledge base. Biotechnology and the pharmaceutical industry share these features. In the second world, R&D is less directly useful and codified knowledge is a small part of the knowledge base. The absence of codification makes horizontal diffusion of the best practical knowledge very difficult. Education is a case in point. Here, formal R&D is of secondary importance; experimentation at the school level and dissemination of new practical knowledge appear as the key features: "To an astonishing degree, the beginner in teaching must start afresh, uninformed on prior solutions and alternative approaches to recurring practical problems" (Latie, quoted in Hargreaves, 1998, p. 6).

These differences are obviously related to the "centre of gravity" of the knowledge base. They indicate that the relative weight of scientific and practical elements in the knowledge base is an essential parameter, one that creates fundamental differences. "In short, I contend that whereas in medicine the full-blown development of an evidence-based approach followed the establishment of a scientific infrastructure to its knowledge base, in the case of education this might be reversed, with the establishment of an evidence-based approach preceding and actively promoting a social scientific infrastructure" (Hargreaves, 1998, p. 18). Of course, such structures are not fixed once and for all. For example, the relationship between scientific knowledge and practical know-how has evolved considerably in materials development and processing: "Until recently, the practitioners of materials engineering remained separated by a wide gulf. Craftsmanship and technology flourished (...). Now, as more becomes known about how processing can modify a material's structure, and thus its properties and ultimately its performance, scientists are becoming more interested in processing and are having more impact on it" (Tidd *et al.*, 1997).

This distinction indicates that, to analyse the knowledge base of the education sector and the biotechnology industry, it is necessary to look at different aspects of the knowledge base. In the education sector, the diffusion of new practical knowledge resulting from experimental learning at the school or classroom level is certainly the key process to be described and measured; in the biotechnology industry, the focus must be the links between universities and private firms. While the conventional indicators that cover formal R&D expenditure and codified outputs (publication, patents) are highly relevant for the biotechnology or pharmaceutical industries, for example, they are almost meaningless for many other sectors.

A second fundamental difference involves degrees of competition in the sector. When a sector is characterised by a high degree of (market or non-market) competition, the functioning of the knowledge base is significantly influenced by the fact that innovation is a precondition for a business's survival; more specifically, the knowledge base's driving force is either the generation of rents from innovation or the dissipation of rents generated by the innovations of rival firms. This gives extraordinary power to the mechanisms developed for absorbing knowledge and for disseminating (whether deliberately or not) best practices and know-how. The absorption of knowledge created by others is an essential function with very substantial spillover effects. Hence, there is a "pool of knowledge" which is automatically maintained by the spillovers which are themselves a result of competition. In sectors that are not fully competitive, such as education and health, the dissemination of knowledge is less automatic, and administrative measures and other incentives aimed at disseminating knowledge will fail to have as much impact as competitive markets. Thus, involuntary spillovers and horizontal knowledge flows are considerably more significant in competitive sectors of the economy.

These two major differences are present in the matrix below, which provides some guidelines for the evaluation and measurement of the knowledge base.

	Competitive environment	Non-competitive environment
Knowledge is poorly articulated (tacit)	Consulting activity	Education (teacher)
Knowledge is highly codified	Biotechnology	Library management

The upper row describes cases in which the relation between research and the production of goods and services is of secondary importance and in which the lack of codification can impede the dissemination and reproduction of knowledge. In the words of Murnane and Nelson (1984), "R&D should not be viewed as creating 'programmes that work'" (p. 367) and provide tidy new technologies to schools, teachers and consultants. In these sectors, R&D "provides a flow of ideas, broadly defined methods" (*ibid.*). Education and consulting are sectors where forms of "tinkering" are the main mechanism for generating knowledge. Hargreaves shows that this is also the case for physicians:

> "Whatever science might contribute to their practice, both doctors and teachers have to exercise considerable professional judgement in making their higher-level decisions; they have to 'read' both client and context and be prepared to adapt their treatment until they find something that 'works' with the client, whether patient or pupil. In short, they learn to tinker, searching pragmatically for acceptable solutions to problems their clients present (Hargreaves, 1998, p. 16)".

The lower row describes cases in which R&D is a key pillar of the innovation system. Deliberate, formal efforts to produce knowledge are taken seriously by entrepreneurs and decision makers, as such efforts are a considerable part of overall innovation efforts. In these situations, companies are eager to link themselves to scientific networks.

Column 2 involves areas where involuntary spillovers are important and determine the existence and growth of a "knowledge infrastructure" (Steinmueller, 1996). In these sectors, the absorptive capacities of firms and the importance of codification are key factors in the distribution of knowledge. However, the current privatisation of the knowledge base may conflict with the distribution of knowledge (David and Foray, 1995; Foray and Mairesse, 1999).

Column 3 covers the opposite case, again clearly illustrated by the education sector. "Much innovation in education, unless mandated, does not get beyond the diffusion phase [*i.e.* is not really adopted and implemented] because insufficient attention is paid to the deep problems associated with adoption, implementation and institutionalisation" (Hargreaves, 1998, p. 20).

Of the four cases, biotechnology and education are the "purest". For each, the questions and issues related to the knowledge base are somewhat different:

– B*iotechnology*: in this quadrant, the centre of gravity of the knowledge base is information and knowledge flows (horizontal and vertical involuntary spillovers; explicit and deliberate relations between university and industry).

– E*ducation*: in this quadrant, the centre of gravity of the knowledge base involves experimental learning at the classroom level. The greatest challenge is to fill the gap between educational R&D and professional practice. Making tacit knowledge more explicit (Hargreaves, 1998, p. 19) and implementing institutional approaches for improving the dissemination of knowledge are important in this respect.

The health sector (physicians) does not fit easily into one of the quadrants: the physician's environment is more competitive than that of a teacher and much of the knowledge base is codified, but "tinkering" remains important. This sector's knowledge base probably has more than one centre of gravity.

With sectoral diversity structured in this way, it is possible to draw attention to various features of the knowledge base which depend on the sectoral context.

Problems linked to the diversity of indicators and measurements

Current work on indicators is quite heterogeneous. To use the image of lighting, certain parts of the knowledge base appear brightly lit; and small sections even seem lit by a laser beam. As a rule, these sections concern research and development and technological innovation. Statistical data on R&D output are thoroughly analysed and examined in highly sophisticated ways (Foray, 1998; OECD, 1997*a*). However, other parts of the knowledge base are not illuminated at all; and the areas neglected are often huge. One that comes to mind is knowledge production and reproduction by service providers – such as physicians and teachers – who do not engage in research and development. Finally, some sections are dimly lit. A weak light is being cast, for instance, on the process of learning by doing in manufacturing industries.

Very few parts of the knowledge base are described in terms of stable categories, *i.e.* through the use of standard and systematic vocabulary such as the R&D categories of the OECD's "Frascati Manual" (1994). In many cases, a stable terminology is lacking. This is the case, for example, for workplace practices and manufacturing skills as Vickery and Wurzburg (1998) stress. They argue that "an improved lexicon of terms is required".

When a section is "brightly lit": *i*) the essential parameters are known, often in great detail; *ii*) the corresponding indicators based on standard categories are available; *iii*) data are collected in a systematic manner; and *iv*) the work in question is often conducted in accordance with international standards.

When a part is "dimly lit", the work is somewhere between stages *i*) and *ii*). A good set of case studies provides a clear understanding of problems. Darkness indicates that the essential parameters – those that underlie a clear reading of the structure and dynamics of the knowledge base – are still being defined.

Table below offers examples of widely differing situations.

Descriptors	Institutions specialising in the production of knowledge	The role of specialised supply sectors (equipment, machinery, ICT)	The role of users
Essential parameter	Public R&D	Diffusion of technology from upstream industries	Importance of lead users
Standard indicators	Public R&D expenditures Output: patents, publications, spillover	Adoption rates of new technologies Embodied technology diffusion	?
Data	Available	Available	Not available

This diversity, which is due to the lack of maturity of the research programme that seeks to measure a knowledge base, is to some extent a constraint, in that the weakest indicators should not be used as the standard for all, nor is it practical to use the most sophisticated as the standard. It is necessary to accept that, for some parts of the knowledge base, and therefore for some parts of the territory under review, there are very detailed maps, whereas for others, there are only rough sketches which may present some broad outlines but which are completely lacking in detail.

The last difficulty arises from the fact that a high degree of heterogeneity inevitably results in the coexistence of different empirical methods. For example, some parts of the knowledge base can be grasped through regression analyses in a production function framework, while others require the use of surveys.

There are two major types of empirical studies (Desrosières, 1989). One has given rise over time to case studies, detailed descriptions of interaction, etc. This type of work resists coding of the information obtained, because coding compartmentalises, flattens and causes some observations to be lost. In addition, it breaks up data on the basis of certain criteria, aspects of a situation or groups which should instead be considered as wholes and perceived and described as such. The second type of approach is basically statistical in nature. It must not be only defined, as is often thought, as a quantifying system, as it also presupposes a concept of the whole (it is exhaustive) and assumes that the cases can be compared analytically as well as in their entirety. The advocates of these methods mainly reproach the case-study approach with an inability to generalise, or to infer, with a given degree of reliability, knowledge applicable to a whole that could be defined in terms of exhaustiveness. The conflict here is not between a micro and a macro approach but between two ways of constructing a whole. Each of these approaches can claim that the other loses sight of the whole, but it is not the same whole. In one case, it is that of an individual or situation which statistical coding mutilates, cuts up and reduces. In the other, it is that of a population, with its precise limits, defined as a logical category.

Yet an obvious aspect of the development of empirical methods, on a given subject, is the gradual transition from a case-study treatment to a statistical approach. In the economics of knowledge, there will therefore be indicators based mainly on the first of these methods, that is, on a case-study view of the whole, as well as indicators based on the second. Moreover, statistical studies are not always "purely" statistical; many have a basis in descriptions or even comparisons and therefore still show some remnants of case-study methods. On the other hand, some research emphasises interaction among variables (this is true, for instance, of econometric studies based on variance analysis) and is considerably "purer", as it lacks any trace of the case study approach.*

The heterogeneity of indicators therefore affects the methodology of empirical research and makes consistent and comparable measurements difficult to achieve. This review considers both "case-study" type indicators as well as statistical indicators. For instance, the relevance and importance of academic research for industry can be estimated through regression analyses in a production function framework (for example, Jaffe, 1989) or grasped more quantitatively through survey research methods (Cohen *et al.*, 1996) or again measured through some statistical methods which still contain traces of case-study methods (Mansfield, 1991). The discrepancies cause a problem, which is due not to the fact that the approaches yield different levels of detail, but rather to the fact that they differ in their empirical methods.

A first report (Foray, 1998) identified three generations of indicators. Here, indicators are selected on the basis not of their generation but rather their relevance and applicability to the issue under study. This makes the problems of diversity even more acute.

Descriptors, essential parameters and indicators for the knowledge base

Three headings for descriptors have been defined:

– Basic attributes of the knowledge base.

– Systems and mechanisms for transferring knowledge.

– Effectiveness of the knowledge base.

Each of the descriptors (D1 to D10) contains several essential parameters.

The basic attributes of the knowledge base

Two parameters of the matrix are involved here, the combination of which makes it possible to characterise certain aspects of the knowledge base (centre of gravity, importance of spillovers and adoption of new knowledge) and thus to have an idea of the main issues to be addressed for measuring the transformation of a knowledge base.

* The development of other statistical methods (factor analysis, correspondence analysis) frequently used in fields such as sociology, implies a degree of compromise between the two approaches. While they entail the use of a series of variables which clearly respond to certain criteria, they nonetheless seek to partially reconstruct wholes of the type found in case studies, either by considering types or by defining areas which have specific consistent features. The manner in which analyses of this type are generally presented is often akin to that used for case studies, in that it seeks to suggest overall consistencies based on groups rather than on variables, as in the case of methods of a more purely statistical nature.

D1. *Codified and tacit knowledge*

The codified or tacit character of knowledge is an essential parameter, in that it is a determining factor in the "reproduction" of knowledge, which influences the conditions under which knowledge can be transmitted, disseminated, reproduced and recorded. In the case of education, for instance "the tacit knowledge of the effective practitioner has to be made more explicit and this is a critical element in successful knowledge creation" (Hargreaves, 1998, p. 19). Codification makes it possible to "liberate" knowledge that is attached to a person. It gives knowledge a high degree of fluidity, of portability, and makes many operations related to problems of mediation and use of knowledge a great deal easier. In the field of health care, in spite of the importance of "tinkering" in interactions between the physician and the patient (see below), there are substantial opportunities for codification. This is evident in the creation and use of technical languages, including by certain categories of patients, the use of evidence-based approaches, the very significant role played by computerisation, the design and intensive use of new tools, all of which require a thorough codification of knowledge (databases, software, expert systems, etc.).

This brings up the critical point of the perception by an observer of what is or is not codified. In the health-care field, much knowledge is codified but the code is not obvious:

> The codebook is not manifest. It is not explicitly consulted, nor in evidence, and an outside observer therefore would have no direct indication of its existence. (To the outside observer, this group appears to be using a large amount of tacit knowledge in its normal operations.) The contents of the codebook in such situations have been so thoroughly internalised, or absorbed by members of the group, that it functions as an implicit source of authority. A "displaced codebook" implies that a codified body of common knowledge is present, but not manifestly so: technical terms figure in descriptive discussion but go undefined because their meaning is evident to all concerned; fundamental relationships among variables are also reiterated in conversations and messages exchanged among members of the group. Identifying such a zone in which knowledge is codified but the existence of codification is not manifest is an extremely important result It raises, however, a very difficult empirical problem of observation (Cowan *et al.*, 1998).

Despite these problems, the dimension of codified knowledge can be approximated by indicators related to the production and use of information and communication technology (ICT) in the sector considered. The number of telecommuters (National Science Board, 1998, pp. 8-27) (as well as some other ICT indicators) could also be used as proxy measures for the codification of knowledge.

Tacit knowledge, as is well known, is not directly measurable. Based on certain observations, some authors have suggested indirect measurements. Their drawback is that they are relatively sector-specific, as in a study by Zucker and Darby (1998), who examine the relationship between the proportion of scientific papers written jointly by new and experienced authors and the degree of tacit knowledge in the sector.

D2. *Competitive vs. non-competitive environment*

There is a great tradition of empirical studies dealing with the measurement of competition intensity in industries. Such approaches are somewhat beyond the scope of our study. Some indicators should, however, be considered to improve our perception about how competitive or non-competitive environment is important for the knowledge creation in a sector.

Feedback and linkages: systems and mechanisms for transferring knowledge

It would be difficult to split up the set of descriptors between entities, institutions and blocs, on the one hand, and transfer and mobility flows, on the other. It would also create redundancies and overlap in the presentation of the descriptors. Thus, it appears more appropriate to analyse the knowledge base as a "*phenomenon of organisational complexity*" from the start and to take a "system-theoretical view" to identify and measure "the interdependence and interactions among the subprocesses in the overall system governing the production, distribution, and utilisation of (scientific and technological) knowledge" (David, 1993, p. 218; see also Soete and Arundel, 1993, Chapter 2). However, the prerequisite for identifying and measuring feedback and linkages is investigation of the blocs themselves.

Seven descriptors (D3 to D9) are identified:

– Feedback and linkages between university/public research and areas of production of goods and services (private firms, schools and teachers, physicians).
– "In-house" learning processes.
– Horizontal diffusion of new knowledge.
– Learning from users, clients, lay people.
– Learning from suppliers of equipment and new technologies.
– Use of new information and communication technologies.
– Pool of knowledge (a way to "aggregate" most of the preceding descriptors).

For each descriptor, essential parameters are identified.

D3. *Feedback and linkages between university/public research and areas of the production of goods and services*

This descriptor refers to the systems and mechanisms for transferring knowledge between university/public research and areas of production of goods and services. As explained above, these systems are the centre of gravity of the knowledge base for sectors such as the pharmaceutical industry, biotechnology or other high-tech engineering activities, while they are less important for some others, such as education. There are in a sense two objectives in terms of measurement and evaluation: first, there is a need to measure vertical spillovers and the impact of academic research on the production of goods or services; second, there is a need for more qualitative description and identification of various patterns of university-industry relationships.

We have identified three essential parameters: *i*) the general context of R&D policy; *ii*) the importance and relevance of academic and public research for the area of production of goods and services; *iii*) the existence of an intermediation space between the two. The table below presents the essential parameters (I, J & K) as well as the corresponding indicators (if any) for the first two of these parameters (levels 1 and 2). Indicators are specified at the second level either when it is valuable to have various kinds of empirical methods or when different indicators describe different dimensions of the phenomenon considered.

Parameter I deals with the general economic context of R&D policy. The corresponding indicators are devised to document possible shifts in policy for support to academic research, possible downsizing of central industrial R&D activities, possible growth of research outsourcing. This is the general context in which the transformation of university-industry relations takes place.

For Ij, the traditional categories used in surveys (basic research, applied research and development) are defined in terms of their distance from commercial applications. However, this distinction is somewhat vague. Moreover, it fails to reflect actual conditions in certain sectors, where pure basic research seems closely related to the market. It is therefore advisable to distinguish, with Nelson and Romer (1996), between basic research whose purpose is to find a practical application and that motivated purely by "curiosity". This makes it possible to identify two types of basic research: pure basic research (without an *a priori* practical purpose) and basic research primarily for practical applications. The distinction is important because it helps prepare for the analysis of situations where basic research is closely connected to the market and obviates the need for a succession of stages between basic research and the market. However, these categories are not yet used for collecting data. The category of applied research and development of course remains.

Parameter J concerns the usefulness of academic and public research for the production of goods and services. Ji involves university research which contributes to industrial R&D through various outputs: new ideas, contribution to the execution of existing R&D projects, prototypes and research techniques and instrumentation. Jj involves various methods for measuring the impact of academic and public research on the productivity of industrial research. They include Jji, estimation of the percentage of industrial inno-

Parameters I, J, K

Parameters	Level 1 indicators	Level 2 indicators
I. General context of R&D policy	Ii. R&D trends by source of support and performing sector (total, industry, public, other non-public)	
	Ij. R&D support and performance by character of work (basic, applied, development)	
	Ik. Growth of research sub-contracting	
J. Importance and relevance of public and academic research for the production of goods or services	Ji. "Useful" outputs of academic research (information, prototypes, problem-solving, instruments)	
	Jj. Social returns to academic research	Jji. Statistical method for measuring externalities percentage of R&D projects using academic results
K. Intermediation	Ki. Discipline or field dedicated to intermediation	
	Kj. Firms' connectedness	Kji. Firm's publications Kjj. Modes of learning about academic results Kjk. Co-patents and co-publications; citation analysis
	Kk. University-industry R&D centres	
	Kl. Spin-offs or public faculty participation in new firms	
	Km. Personnel mobility	Kmi. Labour market statistics Kmj. Survey research methods

vation resulting from recent academic research (Mansfield, 1991) or Jjj, statistical measurement of externalities resulting from university research (Jaffe, 1989).

Parameter K deals with the formation and reproduction of an intermediation space dedicated to facilitating interaction and feedback.

Ki is concerned with the presence or absence of a field or a discipline dedicated to building bridges between academic research and the production of goods or services. Such a field is crucial to the coherence of the knowledge base. It provides for consolidating links between scientific knowledge and practical know-how. In the health-care sector, "(…) the emergence of clinical research and clinical sciences (…) created the crucial mediator between basic science and professional practice" (Hargreaves, 1998, p. 2). Such a field is generally absent in education, so that the connection between scientific scholarship and professional know-how is a weak one (*op. cit.*, p. 18).

Kj is concerned with the fact that, in some cases, companies adopt strategies to increase their connection to the academic system (Cockburn and Henderson, 1997; Hicks, 1995). As Hicks suggests, firms often contribute to scientific publications to make known that they possess knowledge that may interest a scientific partner. Firms with large amounts of publications (Kji) make efforts to be well connected to scientific networks and this tightens their links. Kjj concerns the importance of the different information channels or modes of learning (Cohen *et al.*, 1996): publications, public meetings and conferences, informal information channels, and consulting. Kjk is concerned with the number of co-patents or co-publications developed by enterprises in collaboration with a university or research institute.

Kk involves the amount and economic importance of centres of university-industry research collaboration (Cohen *et al.*, 1994).

Kl is concerned with the importance of spin-offs or faculty/public participation in new firms. In the case of certain sectors, *ad hoc* indicators have been developed (see Zucker and Darby, 1998, for biotechnology), such as the correlation between entrepreneurial and academic achievement.

Km is concerned with mobility of personnel between academic research and production of goods or services and is an essential indicator. The higher the mobility of personnel, the easier it is to combine scientific knowledge and research with practical know-how. It is a crucial attribute of the health care knowledge base (Hargreaves, 1998, p. 5). This type of feedback is very seldom present in education. Hargreaves notes:

> "The absence of feedback from teachers' experience to basic research (because the development of a knowledge-base for teachers was supposed to proceed in linear fashion from the social sciences to application in educational contexts, teachers' craft knowledge was not seen as itself worthy of serious study or formal codification" (*op. cit.*, p. 6).
>
> "Research is not performed by practitioners (*op. cit.*, 10), and many obstacles stand in the way of the development of professor-researchers (*op. cit.*, pp. 14, 15)."

Empirical research has begun on this issue. It is possible to use labour market statistics in order to produce an estimate of the mobility of personnel from the public sector and universities to industry (Sternberg *et al.*, 1996). It is also possible to estimate the share and even the number of practitioners active in research (physician-researchers, educator-researchers, engineer-researchers). The number of doctoral dissertations by employees of business firms serves as an indicator.

D4. *In-house (company, school, medical office) learning processes*

The "in-house" knowledge base – in schools, medical offices, business firms – is the core of industry or services. From the standpoint of the economics of knowledge, it is characterised by the coexistence of deliberate and non-deliberate forms of knowledge generation.

The production of any good (or service) can result in learning and therefore create knowledge. In other words, while the production of knowledge is in many instances not the primary aim, it can nevertheless occur: "the motivation for engaging in the activity is the physical output [or the provision of a service], but there is an additional gain, which may be relatively small, in information which reduces the cost of further production" (Arrow, 1969). These are non-deliberate ways of producing knowledge.

Through this descriptor, issues such as "how to define a school as a learning organisation" (Hargreaves, 1998, p. 22) can be addressed. The answer is based on the analysis of two essential parameters (see table below, "Parameters L &M").

The first refers to a distinction which is now beginning to be made between learning by routine and learning by experimentation. There are forms of learning that are reflected in the fact that the probability of performing a task better is a function of repetition. This routine or myopic type of learning is represented by Wright's curve, formalised in the 1950s. It is universal in that everyone can take advantage of it, from the craftsman to the painter, from the doctor to the nurse. What differentiates sectors, activities or firms from this standpoint is the individual's or the organisation's capacity to recognise, identify and generalise the knowledge produced.

Parameters L & M

L. Experimental learning	Li. Adoption of workplace practices, *e.g.* evolution of hierarchical models of authority	Lii. Econometric analyses on organisational changes and productivity Lij. Survey research method
M. Feedback loops between learning by doing and in-house R&D	Mi. Adoption of workplace practices, *e.g.* horizontal communication and horizontal links; multiskilling and increased job rotation	Mii. Econometric analyses on organisational changes and productivity Mij. Survey research method

Another form of learning consists in experimenting during the production of goods or services (David, 1998). By doing so, one creates new options and variety. This second form of learning is based on a strategy whereby experimentation allows for collecting data, on the basis of which the best strategy for future activities is chosen. This kind of learning depends to a great extent on the nature of the activity. Some activities are high-risk: aeroplane pilots and surgeons cannot make use of this kind of learning. Similarly, a person who controls a railroad switching station or who regulates the circulation of the Parisian *métro* will avoid experiments in the course of his or her normal activity. In all these activities, actors' experiments are limited, because such experiments could conflict with the "normal performance" to be attained.

A professor, instead, can undertake pedagogical experiments; the craftsman can seek new solutions to a problem even during the fabrication process. Being able to undertake this type of learning depends on the nature of the risks involved and also how quickly or how slowly sanctions are applied. The economic context will be very important in this respect. The system of industrial standardisation that is imposed on an activity tells a good deal about how much learning is based on experimentation. Process standards specify not only the result to be obtained but also the way to obtain it. Performance standards leave the choice of the way free, provided that the result is obtained.

The possibility of moving to this second type of learning in many activities represents an important transition in the historical emergence of the knowledge-based economy. In effect, as long as an activity remains fundamentally based on learning processes that are routine adaptation procedures and leave no room for programming experiments during economic activity, there remains a strong dichotomy between those who deliberately produce knowledge and those who use and exploit it. When an activity moves to higher forms of learning, where the individual can programme experiments and obtain results, the production of knowledge becomes much more collectively distributed. That is why the degree of experimental learning as a method of producing knowledge is an essential parameter.

The second parameter deals with the feedback mechanisms and reciprocal links that tie learning by doing and in-house R&D together and by means of which a potentially creative activity effectively contributes to the production of knowledge. The main issue related to this process is to determine the extent to which the knowledge produced "by doing" is valued. However, production activities are rarely considered by firm management as activities that produce knowledge, although there are great disparities in this respect in different national systems. The establishment of feedback loops therefore requires very specific conditions of organisation, which depend notably on effective recognition, identification and valorisation of the knowledge produced through the learning process.

For this portion of the knowledge base, the development of indicators has very far to go. This is not surprising since it requires describing the part of the knowledge base that is kept inside the company, the school or the medical office. There are very few formal and codified inputs and outputs to be measured. "There are many obstacles to developing an empirical basis for discussing changes in strategy, structures, technology, workplace organisation, and human resource management in enterprises and their relationship to each other and to enterprise performance" (Vickery and Wurzburg, 1998, p. 4). The challenge is immense. It is only possible to look to an emerging body of literature containing in-depth and systematic case studies about "how learning by doing is done", modes of experimentation, or "can we learn before doing" (von Hippel and Tyre, 1995; Pisano, 1996; Adler and Clark, 1991; Thomke *et al.*, 1998 ; Argote *et al.*, 1990). We are at a stage where such case studies should encourage statistical agencies to launch programmes to develop indicators and collect data about learning processes and feedback in companies or other organisations. There are very few programmes of this kind. Some surveys on the adoption of workplace practices and the improvement of manufacturing skills are undertaken by some countries in consultation with the OECD/DSTI (Vickery and Wurzburg, 1998). Here again, the situation is far more positive for the manufacturing sector than for the education or health sectors.

D5. *Horizontal dissemination and the reproduction of knowledge*

At issue here is the horizontal dissemination of the "best possible knowledge" or the reproduction of knowledge in areas of production of goods and services. A s already explained, the competitive or non-competitive nature of the environment can make a big difference. In a competitive environment, the high absorptive capacities of firms (developed through various means) lead to a high rate of knowledge dissemination and reproduction (see Mansfield, 1985, on knowledge leakages). In a non-competitive environment, it is difficult to obtain high rates of dissemination.

In general, measures for reproducing knowledge are closely linked to the relationship between scientific knowledge and practical know-how. Whenever tinkering plays a significant role and "knowing what works" is viewed as important by producers of goods and services, "evidence-based approaches" are indispensable if knowledge is to circulate both horizontally and vertically. The dissemination process is relatively effective in health care using evidence-based approaches. It is less so in education.

There are two essential parameters (see table below, "Parameters N & O): one is concerned with the importance of horizontal spillovers and is more relevant to the competitive environment. The corresponding indicators deal with various measures of horizontal spillovers, from statistical methods in a production function framework to survey research methods. The second parameter is concerned with the various organisational strategies that support and facilitate knowledge reproduction by improving absorptive capacities. Of course, many phenomena may fall under this heading. The European Community's Innovation Survey (CIS) has produced a large quantity of information on the various dimensions of absorptive capacity (relative importance of reverse engineering, conferences, journals, fairs and exhibitions, patent disclosures; see Bosworth and Stoneman, 1996).

Three organisational strategies appear to deserve descriptions and measurements. One is the importance of collaborative activities among firms and of institutions and organisations specifically created to address the issue of dissemination of best practice (industrial associations, standardisation committees, schools operating as an experimental network co-ordinated by a university; see Hargreaves, 1998, p. 19). The second involves the mechanisms which support the processes of signalling and reporting the existence of new knowledge (specialised publications, patent databases, information systems). Third, the role of possible mediators and consultants ("knowledge engineers" for Hargreaves, 1998, p. 19) must be taken into consideration. The role of users, lay people and patients (see below), can be significant for disseminating information about best practices.

Parameters N & O

N. Horizontal spillovers	Ni. Measurement of horizontal spillovers	Nii. Statistical measures Nij. Survey research methods
O. Organisational strategies to increase absorptive capacities	Oi. Sources of information for new knowledge and innovation (CIS)	Oii. Collaborative activities, committees, associations, networks Oij. Mechanisms for signalling and reporting knowledge Oik. Mediators, knowledge engineers

D6. *Learning by using and the role of users, patients, lay people*

Demand can play a role in facilitating the diffusion of best practices among suppliers of goods and services. The demand side can also be analysed as an effective contributor to the knowledge base through the mechanisms of learning by using, which is related to specific knowledge of users which enables them to handle specific situations arising from the presence of a new technology at the local level. The importance of the process of learning by using is inseparable from the notion of lead users, a category of actors which, because of the degree of autonomy and latitude they possess for searching for a better use of a complex product (medical tool, scientific instrument, software, machine), play a decisive role in the production of knowledge. Use as a source of innovation has been studied extensively, for example for the sector of scientific instruments (von Hippel, 1988*a*; Urban and von Hippel, 1988).

Studies on national systems of innovation suggest that institutional and organisational forms of learning by using can differ considerably (Lundvall, 1992). Very few studies address the issue of the role of lay people in the dynamics of knowledge (Callon, 1998). There, the degree of codification of knowledge is important: excessive codification would create an obstacle to their appropriation of the field. In the health-care sector, for instance, "it is seen to be the responsibility of lay people to learn the technical language for themselves" (Hargreaves, 1998, p. 7). On the other hand, a lack of codification also creates an obstacle, as the users would not have access to sufficiently explicit knowledge.

There are at least two essential parameters (see table below, "Parameters P & Q"). One is the importance of users as a source of information for innovation. It characterises the links between the areas of use and production and should make it possible to measure the power of learning by using and its feedback to the production area. There are very few relevant indicators. CIS data can provide information about the

Parameters P & Q

P. Users as a source of information for innovation	Pi. Importance of users as a source of information (survey)	
	Pj. Importance of lead users and lead lay people	
Q. Organisational arrangements	Qi. Lay people forums	
	Qj. Users' associations	Qji. Involvement of users in standardisation committees

importance of clients and consumers as a source of information for innovation, but at the present stage good case studies should encourage the development of systematic programmes to develop indicators. New indicators should include the importance of "lead users" (*i.e.* those who are technologically sophisticated and in advance of the market), for example in the engineering sector; Urban and von Hippel (1988) present a methodology for developing such indicators. Indicators should also include "lead lay people", another category in which qualifications are not acquired on the job but rather in a private setting (such as parents of sick children; see Callon, 1998; or citizens wishing to participate in government science policies).

The second parameter deals with organisational arrangements dedicated to improving feedback and linkages. Those arrangements vary markedly across sectors (there are lay forums in the heath care and education sectors and user committees in many manufacturing industries). Involvement of users within standardisation committees is a critical issue in many industries.

D7. *Area for producing high-technology equipment*

Feedback and linkages are especially important for sectors dominated by equipment suppliers, those where the main source of innovation is design of capital goods and intermediary products used to produce goods and services. It is clearly an essential parameter for many industrial sectors (new knowledge is incorporated into capital goods). The area is also important for service sectors, such as health care (new clinical instruments and appliances) and even education: distance education, for example, or after-school tutoring are innovations often based on the creation of new products using information technology.

Two parameters can be identified (see table below, "Parameters R & S"). One is the dissemination of technology as new equipment and machinery. Relevant indicators derive from different empirical methods, one involving the adoption rate for new technologies, as estimated through firm surveys, the other embodied technology diffusion, as assessed through input-output matrices which track the exchange of goods among industrial sectors with different R&D intensities. In the second case, purchased inputs act as carriers of technology across sectors (OECD, 1997).

The second parameter addresses the institutional arrangements dedicated to improving the relations between equipment suppliers and a given industry. For instance, SEMATECH is a consortium created to this end by the main actors in the US semiconductor industry (Grindley *et al.*, 1996). Any

Parameters R & S

R. Dissemination of technology	Ri. Adoption rate of new technologies (firm survey)
	Rj. Technology diffusion (input-output matrix)
S. Organisations	Si. Consortia

committee or industrial association which allow firms to undertake collective action to improve industry relations with the supply side (which are an industry-specific public good) should be considered.

D 8. *The use of new ICTs*

New information and communication technologies are an essential determinant of the dynamics of the knowledge base in any sector. They provide considerable opportunities for expanding and making fuller use of the knowledge base (databases, virtual libraries, electronic archives for images, electronic communication and transfer of data, etc.). Two parameters are proposed (see table below, "Parameters T & U"):

– The use of ICT to produce new forms of codified knowledge (software, databases).

– The influence of ICTs on the constitution and functioning of networks that transmit knowledge. In general, geographical distance diminishes the intensity of use of external knowledge. The effects of the geographical location of spillovers (from universities to industry, among firms) are very significant (Henderson *et al.*, 1993). The use of ICT is assumed to lower the negative influence of distance on the functioning of networks.

Many indicators are being designed and are already in use in certain countries (OECD, 1997*b*). A sort of information technology metrics has been developed (National Science Board, 1998, pp. 8.33): index of IT investments by industry; intensity of use of electronic networks by sector, software R&D by sector, end use of semiconductors by sector. Moreover, tables of inter-industry transaction flows make it possible to calculate embodied knowledge flows from ICT sectors (office machine and computers, telecommunication devices, communication services) to all other economic sectors.

In terms of the influence of ICT on the codification of knowledge and the dispersion of activities, initial econometric work confirms the correlation between the codifiability of knowledge and the geographical dispersion of research organisations (Feldman and Lichtenberg, 1996). *Ad hoc* indicators exist, such as the significance of distance learning in the education sector.

Parameters T & U

T. Use of ICTs to produce new forms of codified knowledge	Ti. Inter-industry transaction flows
	Tj. IT metrics: new products (software, databases); software R&D by sector
U. Use of ICTs to transmit knowledge	Ui. IT metrics: intensity of electronic network usage by sector
	Uj. Econometric analyses on correlation between codified knowledge and geographical dispersion

D 9. *Synthesis: the pool of knowledge*

All of the preceding parameters, which characterise the mobility and transfer of knowledge, can be summarised in a general "pool-of-knowledge" parameter. This is the stock of knowledge of record. The notion of "reported or recorded knowledge" is important, as it allows for including in the knowledge pool any kind of knowledge (public or private, codified or tacit), provided that it is reported, either by full or partial diffusion. This recorded knowledge can have two forms. It can result from the effective dissemination of knowledge, which provides other parties with complete information about the knowledge under consideration; this is done principally through the publication of scientific results and the granting of technological licenses. Or it can come from the issuing of signals enabling third parties to learn about the knowledge but not to acquire it fully; however, because of the signals, third parties can contact the issuer and possibly arrive at an agreement on the transfer or sharing of the knowledge. Databases on patents provide this type of signal, as do publications containing news about research in progress. As part of the knowledge pool, tacit knowledge is more problematic. Although it may be swapped in transactions resembling exchanges of gifts or sold for money, rather than being freely shared, its tacitness impedes efficient dissemination (David and Foray, 1995).

Dissemination of knowledge may be deliberate. For example, Hicks (1995) demonstrated that the publication in academic journals of research by corporate researchers is justified mainly by the need to attract university researchers by sending a signal; the act of publishing signals the existence of knowledge in the firm to which university researchers may have access if they decide to collaborate. The deliberate dissemination of knowledge through the issuing of signals has become increasingly organised and systematic owing to the creation of "information systems on R&D".

The dissemination of knowledge may not be deliberate. There are mechanisms for reverse engineering as well as informal exchange networks which have involuntary spillover effects (von Hippel, 1988). The mobility of personnel is a crucial and most often non-deliberate factor in transferring tacit knowledge (see table below).

	Effective diffusion	Signals
Deliberate	Scientific publication Technology licensing	Patent disclosures Information systems on research Fairs, exhibition
Non deliberate (involuntary spillovers)	Reverse engineering Mobility of personnel	Information sharing through informal networks

Measuring items in each quadrant would give a better picture of the pool of knowledge in a given sector. An example of statistical work in this vein is the use of data on patents and patent citations to model knowledge flows (Jaffe and Trajtenberg, 1996).

The existence of a pool of knowledge that includes knowledge which is effectively disclosed and knowledge which is signalled does not mean that identifying, evaluating and integrating external knowledge carries no costs. The costs of searching out information can be high. They are determined by the dispersion and the division of the knowledge base: "(...) division of knowledge, like division of labour, refers to the fact that individuals have acquired different skills, mastered different specialities, and developed different interests and inclinations. Dispersion of knowledge refers to the particular circumstances of time and place; this knowledge of momentary local situations – matters that are important for efficient allocation of resources but which cannot be included in reports to the planning commission" (Machlup, 1984, p. 189).

These are two essential parameters, in the sense that the extent of division and dispersion are indicative of problems of "attention management" and information asymmetries, which can stand in the way of the best possible use of a knowledge base. Barabaschi (1992) sketches out some indicators in this connection, by measuring the importance of key lateral technologies for a firm (in this instance, Ansaldo) and the volume of published technical data that is relevant for that firm. Even if the issue of measuring the degree of division and dispersion of knowledge is not touched upon, expert opinion provides useful indications about these dimensions of the knowledge base. For instance, in the case of health care, the division of knowledge is very extensive, as Henderson (1994) notes. The dispersion

Parameters V, W, X & Y

V. Deliberate dissemination	Vi. Through effective diffusion	Vij. Scientific publications Vij. Technology licensing
	Vj. Through emission of signals	
W. Involuntary spillovers		
X. Dispersion of knowledge		
Y. Division of knowledge		

of the knowledge base is also considerable, in particular for everything pertaining to medical practices (see table, "Parameters V, W, X & Y").

The effectiveness of the knowledge base

These parameters are concerned with the ability to innovate and the ability to provide expertise, as well as the degree of internationalisation of the knowledge base. For reasons of length, the focus here is on the rate of innovation (but complementary information will be provided during the conference).

D10. *Innovation rate, obsolescence and knowledge intensity*

The essential parameters concern the rate of innovation (intensity of change) and the radical nature of the innovation.

The first indicator that appears needed would make it possible to gauge the nature of the innovation or its "radical novelty". The following categories can be used and allow for knowing if the innovation is more an adaptation (of existing technologies) or a case of radical novelty:

– New for the company and new to the market.

– New for the company but existing on the market.

– Adaptation of existing product for new market.

– Adaptation of existing product on existing market.

The second indicator should give the intensity or the speed of change. In practice, of course, it is not easy to distinguish between an increase in the innovation rate and a shortening of the time to market entry. However, one should consider the following available indicators: share of new products in total sales and CIS data on the number of realised and projected innovations.

The indicator proposed by Carter (1994*a*) should also be kept in mind, at least for manufacturing sectors. It is based on the assumption that there is a strong correlation between the proportion of workers not directly involved in production and the rate of change in the sector. Workers who are not directly assigned to a production task are defined as the "agents of change"; their role is to prepare changes and facilitate the necessary adaptations and adjustments. In manufacturing sectors that innovate little, the share of this category of workers is 20%, while it can reach up to 80% in the case of very innovative sectors. Carter then interprets the evolution of the structure of manufacturing employment in the United States, which reveals strong growth in the share of this category of workers, as a sign of accelerating change.

The importance of innovation costs as compared to total costs is another means of addressing the question of the intensity of change. Carter (1994*b*) distinguishes intangible investment costs, replacement (and flexibility) costs, and the virtual costs of inexperience. In most sectors, the share of these costs is rising significantly. In some sectors, they can represent up to 90% of total costs, with the remaining 10% used for what was previously the main task, that of maintaining what already exists. The CIS survey also allows for evaluating innovation costs.

Finally, the best overall indicator is undoubtedly the one that "merely" measures the knowledge intensity of economic activities (see table below, "Parameter Z"). The assumption is that knowledge intensity reflects the level of competencies needed to innovate, react to change, and be mobile, multiskilled and creative. As compared to the work of Machlup (1984), which identified a sector specialised in knowledge, Eliasson (1990) proposes a significant theoretical and methodological renewal. It consists in considering that the tasks of producing knowledge and processing information are found in all economic activities, including those of low technological intensity. In other words, the increase in the knowledge intensity of the economy is due less to the continuous expansion of a specialised sector than to the proliferation of knowledge-intensive activities in all sectors of the economy. The taxonomy of activities developed by Eliasson is functional. It covers all the operations that, in any sector of activity, have knowledge production and processing content. These operations include, in particular, the following categories:

– Creation of new knowledge: R&D, design.

– Economic co-ordination: marketing, distribution, administration.

– Internal transfer of knowledge: training.

Parameter Z

Z. Innovation and knowledge intensity	Zi. Nature of the innovation	
	Zj. Intensity and speed of change	Zij. Number of realised and projected innovations Zij. Share of new products in total sales Zik. Share of "agents of change" Zil. Innovation costs
	Zk. Knowledge intensity	Zki. Knowledge intensive tasks Zkj. Knowledge intensive expenditures

In this new framework, Eliasson shows that in the United States in 1980, 45.8% of working hours were devoted to knowledge-intensive activities (compared to 30.7% in 1950).

There is, as a result, a certain standardisation of the framework for measuring knowledge-based activities for a given country or sector, which makes it possible to calculate the share of investment devoted to knowledge. Expenditures on R&D, software, marketing, transfer of knowledge and education are the main items of intangible capital; computers and telecommunications expenditures are the two components of tangible capital to be considered (Mine, 1996).

Conclusion

The report gives a framework for analysis and a set of possible indicators for characterising the transformation of a given sector's knowledge base. It also points at areas where indicators of knowledge are partly or wholly lacking. The report is preliminary, and there may be other frameworks for understanding and measuring the production, mediation and use of knowledge in different sectors.

The discussion in the first section stresses two kinds of obstacles that impede the development of a complete set of indicators that would be compatible and appropriate for any sector of activity. The first problem relates to the very diverse sectoral situations of knowledge production, mediation and use; the second is the heterogenity of indicators and measurement itself.

The second section presents ten key descriptors of a sector's knowledge base under the headings of *i)* basic attributes of the knowledge base; *ii)* systems and mechanisms for transferring the knowledge base; and *iii)* effectiveness of the knowledge base. Each of the descriptors contains some essential parameters. Standard indicators (if any) are discussed and listed.

Several international and national organisations and research teams are working on addressing these issues, including the OECD and the NSF. This report offers a sort of overall (systemic) logic for measuring the transformation of a sector's knowledge base. Furthermore, the framework aims at embracing a far wider range of human activities than is conventionally done in empirical studies of knowledge. It would be worthwhile to examine further the issues and questions addressed here.

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