Knowledge Management

Innovation in the Knowledge Economy

IMPLICATIONS FOR EDUCATION AND LEARNING

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CENTRE FOR EDUCATIONAL RESEARCH AND INNOVATION

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The main objectives of the Centre are as follows:

– *analyse and develop research, innovation and key indicators in current and emerging education and learning issues, and their links to other sectors of policy;*
– *explore forward-looking coherent approaches to education and learning in the context of national and international cultural, social and economic change; and*
– *facilitate practical co-operation among member countries and, where relevant, with non-member countries, in order to seek solutions and exchange views of educational problems of common interest.*

The Centre functions within the Organisation for Economic Co-operation and Development in accordance with the decisions of the Council of the Organisation, under the authority of the Secretary-General. It is supervised by a Governing Board composed of one national expert in its field of competence from each of the countries participating in its programme of work.

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FOREWORD

Today's "knowledge economies" are seeing the emergence of new paradigms for innovation and the advance of knowledge in relation to economic production. This is not because either knowledge or innovation are new ingredients of economic growth. Rather, against a background of a rapid acceleration in the development of knowledge, a revolution in the instruments of knowledge and a necessary redefinition of some of the components of knowledge, the drivers of knowledge advance are also inevitably changing. This report explores some key determinants of innovation in these new circumstances and their implications for the advance of knowledge in a particular sector – primary and secondary education.

This analysis shows that while on the one hand, there is considerable scope for the same drivers that have helped speed up innovation elsewhere to take effect in education, on the other, in practice, a number of characteristics built into education systems have so far helped prevent the nature of innovation in this sector from changing fundamentally.

Chapter 1 starts by setting out very broadly some economic fundamentals that operate today in our knowledge-based societies.

Chapter 2 focuses more specifically on four sources of innovation and the potential capacity of the education sector to develop them. The four sources are: science, users and doers of practical experiments, modular structures in industrial systems and ICTs. The important thing for policy makers is not to neglect the potential usefulness of any of these sources as four prime drivers of innovation in the knowledge economy.

Public availability of knowledge plays an essential role in all four of these aspects of innovation, and Chapter 3 goes on to look at the particular issue of the public and private ownership of knowledge as a key feature of knowledge economies. It argues that a crucial issue facing governments today is to find ways of reclaiming a public dimension to knowledge in what has essentially been a privatised knowledge revolution. It looks at the possibility that the privatisation of knowledge represented by an expanded use of patenting becomes a serious issue in the education sector, and suggests therefore that reformulating the importance and boundaries of a public dimension to knowledge could become important to the education industry just as it has in areas such as health care.

Professor Paul A. David (University of Oxford, United Kingdom and Stanford, United States) and Professor Jacques Mairesse (EHESS, France) have been particularly involved in the design and development of the project; Professor David Hargreaves (University of Cambridge, United Kingdom) has written the policy document related to the UK experience.

Depth studies for this project have been carried out by Professors Balconi, Blume, Cockburn, King, Mansell, Uhlir and von Hippel. The full studies can be read in downloadable working papers, as referenced.

Principal Analyst Dominique Foray from the OECD Secretariat has been responsible for conceptualising and managing the project.

This book is published on the responsibility of the Secretary-General of the OECD.

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EXECUTIVE SUMMARY

Most sectors and industries in the knowledge economy are currently experiencing a “Schumpeterian renaissance”: innovation is today the crucial source of effective competition, of economic development and the transformation of society. Does this renaissance extend to the education sector? The answer must be “not yet”, to the extent that efforts to implement change in the name of “educational improvement” have aimed mainly to raise the effectiveness of the system at the margin without trying to move the system into a new era. This report aims at helping all stakeholders in education systems to consider seriously the principles of the Schumpeterian renaissance in relation to the organisation and evolution of educational activities, and to design policy actions accordingly.

The report identifies, with reference to case studies documented in the Centre for Educational Research and Innovation (CERI) project, “Promoting the Economics and the Management of Knowledge”, four key factors that are becoming important drivers of innovation in the economy generally. In describing the various factors needed to fully realize innovative capacity, this report looks at the sources of innovation. The four innovation sources are:

- science: science plays an unquestionable role in advancing knowledge. It has been the slow expansion of the model of “science illuminating technologies and practices” that has spawned innovation in many sectors of the economy;

- users and doers: new actors are becoming engaged in innovation processes, and this creates new opportunities. The impact of users and doers on innovation is greater when they share: there are freely revealing their knowledge and, thus, work cooperatively;

- modular structures: the increasing importance of complex systems in which innovation creates a lot of instability and unbalance requires the creation of modular structures, each with freedom to innovate, yet joined together in a whole innovative system;

- information and communication technologies (ICTs): ICTs are the general purpose technology at the information age and as such create numerous opportunities to transform products, processes and organisations in the whole economy.

Having built such a framework for analysing and assessing the innovation capacity in any sector of the economy, the report focuses, then, more specifically on the education sector. It discusses the potential impact of the four sources of innovation on the transformation of the sector. It, therefore, provides a clear figure about where the education sector stands with regard to the four sources of innovation and derives policy issues. The report shows, for instance, that ICTs and horizontal networks among doers (*i.e.* teachers) seem to have been more widely used than scientific research and modularity as a method to enable innovation.

This report has not tried to imply that every source will be equally relevant for each aspect of educational innovation, but rather that each source's potential needs to be explored in order to optimise the strength of innovation in a sector in which steady improvement in performance has become a priority.

Last but not least, the report discusses some common features of the four sources such as the importance of the public dimension of knowledge as a key determinant of the efficiency of any innovation process.

INTRODUCTION

Today's "knowledge economies" are seeing the emergence of new paradigms for innovation and the advance of knowledge in relation to economic production. This is not because either knowledge or innovation are new ingredients of economic growth. Rather, against a background of a rapid acceleration in the development of knowledge, a revolution in the instruments of knowledge and a necessary redefinition of some of the components of knowledge, the drivers of knowledge advance are also inevitably changing. Thus, the process of inventing, developing and bringing to users a 21^{st} century microelectronic product is very different from the equivalent process in the case of, say, the light-bulb in the 19^{th} century.

This report explores some key determinants of innovation in these new circumstances and their implications for the advance of knowledge in a particular sector – primary and secondary education.

This analysis shows that while on the one hand, there is considerable scope for the same drivers that have helped speed up innovation elsewhere to take effect in education, on the other, in practice, a number of characteristics built into education systems have so far helped prevent the nature of innovation in this sector from changing fundamentally.

Chapter 1 starts by setting out very broadly some economic fundamentals that operate today in our knowledge-based societies. It argues that a number of factors are becoming more important to innovation, among them:

- the interaction between people in communities of knowledge;
- the capacity of different sectors to "codify" or make explicit the often deeply embedded knowledge that can contribute to economic advance; and
- the relationship between the public aspects of knowledge that allow it to spread and the private features that give an incentive to private agents to produce it in the first place.

Chapter 2 focuses more specifically on four sources of innovation and the potential capacity of the education sector to develop them.

The first is scientific knowledge, which needs to be combined effectively with technology and with applications in order to stimulate industrial innovation. In the education field, experimental science has made limited impact but could make more; however there is a tension between those who emphasise explicit knowledge formulated as the results of scientific experiment and those who think knowledge acquired through teaching practices and held by expert practitioners is the key.

The second source of innovation is generated by the involvement of "users and doers", which has become vitally important in a number of sectors, but requires incentives by users/doers to try new things and to share their expertise with others. In education the second of these conditions is more elusive than the first.

Thirdly, relationships between decentralised, "modular" units authorised to innovate and a whole co-ordinated system help determine the scope for rapid and effective innovation. In particular, complex systems may innovate more effectively in a highly decentralised model. Education systems are highly complex, but there are various obstacles to decentralised innovation, and so far the rules of this game tend to have been controlled from the centre.

Finally, information and communication technologies offer a powerful new instrument for innovation, but only in sectors where there is a willingness to discard certain conventional ways of doing things: this has so far not been the case in the education sector.

Public availability of knowledge plays an essential role in all four of these aspects of innovation, and Chapter 3 goes on to look at the particular issue of the public and private ownership of knowledge as a key feature of knowledge economies. It argues that a crucial issue facing governments today is to find ways of reclaiming a public dimension to knowledge in what has essentially been a privatised knowledge revolution. It looks at the possibility that the privatisation of knowledge represented by an expanded use of patenting becomes a serious issue in the education sector, and suggests therefore that reformulating the importance and boundaries of a public dimension to knowledge could become important to the education industry just as it has in areas such as health care.

Chapters 1 to 3 draw on a series of depth studies that look at specific ways in which knowledge systems operate, within and across sectors. These studies were produced by experts during the course of CERI's project on innovation, carried out primarily in 2002. The present report draws attention to selected findings from these studies; the full studies can be read in downloadable working papers, as referenced.

MAPPING INNOVATION: EIGHT DEPTH STUDIES *www.oecd.org/edu/km/mappinginnovation*	
E. von Hippel	"Open Source Projects as Horizontal Innovation Networks – By and for Users" (Box 1.1)
M. Hedstrom and J.L. King	"On the LAM: Library, Archive and Museum Collections in the Creation and Maintenance of Knowledge Communities" (Box 1.2)
R. Mansell and R. Curry	"Emergency Healthcare: An Emergent Knowledge-driven System" (Box 2.1)
M. Balconi and A. Centuori	"On the Creation and Distribution of Knowledge in Microelectronics" (Box 2.2)
S. Blume	"Patients, Patient Organisations, and the Production of Medical Science and Technology (Box 2.3)
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CHAPTER 1
ECONOMIC FUNDAMENTALS OF THE KNOWLEDGE SOCIETY

This chapter provides an introduction to fundamental issues in the development of new knowledge-based economies. After placing their emergence in historical perspective and proposing a theoretical framework that distinguishes knowledge from information, it characterises the specific nature of such economies. It goes on to deal with some of the major issues concerning the new skills and abilities required for integration into the knowledge-based economy; the new geography that is taking shape (where physical distance ceases to be such an influential constraint); the conditions governing access to both information and knowledge, not least for developing countries; the uneven development of scientific, technological (including organisational) knowledge across different sectors of activity; problems concerning intellectual property rights and the privatization of knowledge; and the issues of trust, memory and the fragmentation of knowledge.

1.1. Introduction

With the notion of knowledge society, economists wish to introduce the idea of a break in growth processes and modes of organisation of the economy. It can therefore give rise to skepticism, for knowledge has always been at the heart of economic development. The ability to produce knowledge that is then embodied in products, processes and organisations, has always served to fuel development. This chapter aims, therefore, at showing that something "new" is happening, a change from the economies of earlier periods, but more a "sea-change" than a sharp discontinuity.

1.2. Historical perspective

Knowledge has been at the heart of economic growth and the gradual rise in levels of social well-being since time immemorial. The ability to invent and innovate, that is to create new knowledge and new ideas that are then embodied in products, processes and organisations, has always served to fuel development. And there have always been organisations and institutions capable of creating and disseminating knowledge: from the medieval guilds through to the large business corporations of the early 20th century, from the Cistercian abbeys to the royal academies of science that began to emerge in the 17th century. “Knowledge-based economy”, however, is a recently coined term. As such, its use is meant to signify a change from the economies of earlier periods, more a “sea-change” than a sharp discontinuity. This transformation can be analysed at a number of different levels.

The acceleration of knowledge production

The crux of the issue lies in the accelerating (and unprecedented) speed at which knowledge is created, accumulated and, most probably, depreciated in terms of economic relevance and value. This trend has reflected, *inter alia*, an intensified pace of scientific and technological progress. It has a host of ramifications and gives rise to many new challenges. But the discontinuity is not equally pronounced in every sector. A new kind of organisation is spearheading the phenomenon: knowledge-based communities, *i.e.* networks of individuals striving, first and foremost, to produce and circulate new knowledge and working for different, even rival, organisations. One sign that a knowledge-based economy is developing can be seen when such individuals penetrate conventional organisations to which their continuing attachment to an “external” knowledge-based community represents a valuable asset. As members of these communities develop their collective expertise, they become agents of change for the economy as a whole (see below).

The rise of intangible capital at macroeconomic level

Economic historians point out that nowadays disparities in the productivity and growth of different countries have far less to do with their abundance (or lack) of natural resources than with the capacity to improve the quality of human capital and factors of production: in other words, to create new knowledge and ideas and incorporate them in equipment and people.

A related characteristic of economic growth, that became increasingly evident from the early 20th century onwards, is the growing relative importance of intangible capital in total productive wealth, and the rising relative share of GDP attributable to intangible capital (Abramovitz and David, 2000). Intangible capital largely falls into two main categories: on the one hand, investment geared to the production and dissemination of knowledge (*i.e.* in training, education, R&D, information and coordination); on the other, investment geared to sustaining the physical state of human capital (health expenditure). In the United States, the current value of the stock of intangible capital (devoted to knowledge creation and human capital) began to outweigh that of tangible capital (physical infrastructure and equipment, inventories, natural resources) at the end of the 1960s.

Recent work by OECD has helped produce stable categories of knowledge-related investment for given countries or sectors. Taking the simple yet highly restrictive measure of investment in research and development, public education and software, one can see that annual investment rates have grown strongly since the 1980s (at an average annual rate of 3% in the OECD countries). Investment structures, however, differ from one country to the next: Scandinavian countries, for instance, spend more on public education, while industrial investment (private-sector R&D, software and information technology equipment) tops the list in the United States (OECD, 1999).

This basic underlying trend must not be allowed to obscure the growing importance of science and technology-related activities. Knowledge-based economies are not, of course, restricted to the realm of high technology, but science and technology do tend to be central to the new sectors giving momentum to the upward growth of the economy as a whole over the past few decades (pharmaceuticals and scientific instrumentation, information and communication technologies, aeronautics, new materials).

These developments are reflected in an ever-increasing proliferation of jobs in the production, processing and transfer of knowledge and information. This trend is not just confined to the high-technology and information and communication service sectors as it has gradually spread across the entire economy since first coming to light as early as in the 1970s. Society as a whole, then, is shifting to knowledge-intensive activities.

Innovation is becoming the dominant activity, four sources are increasingly important

Another reflection of the aforementioned "gear change" is the growing speed and intensity of innovation. There are four main ways in which breakthroughs come about:

- first, through formal research and development work *off-line* (*i.e.* "isolated" and "sheltered" from the regular production of goods and services);

- second, through learning *online*, where individuals learn by doing and, as a rule, can assess what they learn and hone their practices for what follows next. This can be an extremely potent form of knowledge production in many professions;

- third, through the full realisation of the potential benefits generated by the modular structures of technological systems;

- fourth, through the "invention" and development of ICT's based systems as a way to regenerate activities.

Chapter 2 will address specifically the issue of fully exploiting the four sources of innovation and discuss their relevance to the education sector.

Significantly increasing investment in innovation (not least in R&D) has sent the numbers of innovations appearing soaring, as evidenced not only by the volume of patents requested and approved (OECD, 1999), but also by the proliferation of new varieties of goods and services that has marked the trend toward "mass customisation" (see David, 2000). At the same time, practice-based learning environments appear to be broadening out from situations where Fordist divisions of labour in offices and factories reduced the individual's scope of activity and, hence, opportunity to learn. This, in turn, is fostering ever-greater possibilities for knowledge creation.

Meanwhile, the "need to innovate" is growing stronger as innovation comes closer to being the sole means to survive and prosper in highly competitive and globalised economies. It is not easy to distinguish between absolute novelties ("under the sun") and innovations that are new only to the companies that adopt them, or more complex adaptations of existing products or ideas to a new market. The fact remains that companies and society in general are spending more time and energy on producing and adjusting to change.

Formal research may remain the cornerstone of knowledge production in many sectors (for the simple reason that it provides a more or less sheltered domain in which to carry out experiments that would not otherwise be possible in real life). But the knowledge production system is becoming more widely distributed across a host of new places and actors. More and more "innovators" tend to be appearing in unexpected situations: users as the source of innovation (von Hippel, 1988a), "lay people" involved in the production of scientific knowledge within such realms as health and the environment.

The revolution in instruments of knowledge

The fourth level at which the “soft discontinuity” can be analysed concerns the major technological revolution that is taking place as we enter the digital age. It is a revolution of crucial importance in that it basically involves technologies for knowledge and information production and dissemination. These new technologies, which first emerged in the 1950s and then really took off with the advent of the Internet, have breathtaking potential. They enable remote access to information and the means of acquiring knowledge. In addition to transmitting written texts and other digitisable items (music, pictures), they also allow users to access and work upon knowledge systems from a distance (*e.g.* remote experimentation), to take distance-learning courses within the framework of interactive teacher-student relations (tele-education) and to have unbelievable quantities of information – a sort of universal library – available on their desktops.

In the past 15 years spectacular advances have been made in some types of jobs which are, in a sense, pioneers in the economics of knowledge (researchers, teachers and students, journalists and documentalists, architects, designers and engineers, jobs based on the ability to research, compare and interpret facts and evidence – medicine, law –, people in charge of libraries, archives and museums, etc.). It seems that new sections of the population, employed in activities less directly related to processes of creation, transmission and conservation of knowledge, will progressively be affected by technological advances (depending, fundamentally, on the extension and continuation of the first trend described – the widening of human capital).

In the next chapter, ICTs will be treated as one of the main sources of innovation for any sector of activity.

Five years of the “new economy” – viewed in historical perspective

Now that the emergence of knowledge-based economies has been put into historical perspective, the new economy debate can only be viewed with a degree of amusement. It has focused on the possible need for a radical reform of macro-economics because the dominant tenets of that field appeared to have been surprised by the American economy’s performance during the last half-decade of an entire millennium. Overall, this debate will mainly be remembered for the clash between the ultra-optimists and their relatively crude economic thinking, and the sceptical macroeconomists who, despite their usual rigour and prudence, have an extremely partial and truncated view of the impacts of new technologies (Gordon, 2000). Yet it is not what the United States and, more recently, European and other Western countries have been experiencing just part of an accelerating transition to the knowledge-based economy, a process that began quite some time ago but which only started gathering momentum fairly recently owing to the slow maturation of the new, general-purpose technology of digital information processors and computer-mediated telecommunications (David, 1990, 2000).

1.3. Exploring the black box of "knowledge"

Before going on to describe the workings of a knowledge-based economy, it is important to have a clear idea of exactly what it is that is passing through the electronic pipelines: knowledge, information or data? Something of each, actually. It all depends on the nature of the relationship between the senders and recipients.

Knowledge and information

A basic distinction should be drawn between knowledge and information. Knowledge – in whatever field – empowers its possessors with the capacity for intellectual or physical action. So what we mean by knowledge is fundamentally a matter of cognitive capability. Information, on the other hand, takes the shape of structured and formatted data that remain passive and inert until used by those with the knowledge needed to interpret and process them. The full meaning of this distinction becomes clear when one looks into the conditions governing the reproduction of knowledge and information. While the cost of replicating information amounts to no more than the price of making copies (*i.e.* next to nothing thanks to modern technology), reproducing knowledge is a far more expensive process because some, indeed many, cognitive capabilities are not easy to articulate explicitly or to transfer to others. There are elements that therefore remain "tacit": "we know more than we can say" (Polanyi, 1967). Knowledge reproduction has therefore long hinged on the "master-apprentice" system (where a young person's capacity is moulded by watching, listening and imitating) or on interpersonal transactions among members of the same profession or community of practice. These means of reproducing knowledge may remain at the heart of many professions and traditions, but they can easily fail to operate when social ties unravel, when contact is broken between older and younger generations and when professional communities lose their capacity to act in stabilising, preserving and transmitting knowledge. In such cases, reproduction grinds to a halt and the knowledge in question is in imminent danger of being lost and forgotten.

The French language (as well as many others) offers a distinction between "savoir" and "connaissance" that has no real equivalent in English, though it can be conveyed by adding the qualifier "reliable". Reliable knowledge ("savoir") means certified, robust knowledge that has been legitimised by some institutional mechanism (be it scientific peer review or collective memory and belief systems). Other forms of knowledge ("connaissance") also enable action (knowing how to do the gardening, DIY) but have not been put through the same tests as certified knowledge. What separates the two has less to do with a contrast between the scientific and non-scientific than whether or not the knowledge has been subjected to institutional testing: "gardening knowledge" is reliable, wide-ranging and relatively decontextualised, but each gardener has his or her own local (and locality-specific) knowledge. Yet the knowledge-based economy does not preclude either form, meaning that it is not geared solely to the formal production of "reliable knowledge".

Codification of tacit knowledge

On the other hand, knowledge may be codified: so articulated and clarified that it can be expressed in a particular language and recorded on a particular medium. Codification involves the exteriorisation of memory. It hinges on a range of increasingly complex actions such as using a natural language to write a cooking recipe, applying industrial design techniques to draft a scale drawing of a piece of machinery, creating an expert system from the formalised rules of inference underlying the sequence of stages geared to problems and so on. As such, knowledge is detached from the individual and the memory and communication capacity created is made independent of human beings (as long as the medium upon which the knowledge is stored is safeguarded and the language in which it is expressed is remembered). With the emergence of codification, "the problem of memory ceases to dominate intellectual life" (Goody, 1977). Learning programmes are then produced that *partially* replace the person who holds and teaches knowledge. Goody (1977) notes that a written recipe can partially fill up the empty space created by the absence of the grandmother.

"Partially" is the key word here because for codification amounts to the process of reducing human knowledge to information, and in the course of such transformations some things almost certainly something will be altered, and, quite likely, other meanings will be lost. What is expressed and recorded, then, is not complete knowledge. It is a learning programme that helps to stabilise and reproduce knowledge. When a young technician receives a user's manual, he or she is not directly given knowledge on "how to run the machine". That said, the manual is helpful and will serve to reduce the costs of knowledge reproduction.

In many cases, when technicians have "learned to learn" and are dealing with a more or less standard machine, knowledge reproduction becomes almost instantaneous and assumes characteristics close to those of information reproduction. In more complex cases, however, the codified knowledge, while certainly useful, will only provide partial assistance. Knowledge reproduction will then occur through training, practice and simulation techniques (aircraft pilots, surgeons).

There is, it must be stressed, a second and, in our view, crucial function of codification. Codification consists in translating knowledge into symbolic representations so that it can be stored on a particular medium. This creates new cognitive potentialities that remain inconceivable so long as the knowledge is attached to individual human beings and, hence, only heard (when spoken) or seen (when put into practice) through interaction with those carriers. Inscribing (through writing, graphics, modelling, virtuality) makes it possible to examine and arrange knowledge in different ways and to isolate, classify and combine different components. This leads to the creation of new knowledge objects such as lists, tables, formulae, etc. These are fundamentally important in that they open up new cognitive possibilities (classification, taxonomy, tree networks, simulation) that can provide a framework for the rapid production of new knowledge (Goody, 1977). But they are only possible when people consider the matter of recording and, hence, the symbolic representation of their cognitive states. Advances in information technology-based recording methods are crucial here, for they allow representations of knowledge to progress from the so-called “pre-literate” stage (gestures and words) to the literate (writing and drawing) and then post-literate stages (modelling structured interactions).

Codification thus plays a central role in the knowledge economy because it serves to further memorisation, communication and learning, and forms a sound basis for the creation of new knowledge objects.

1.4. Knowledge-based communities as agents of economic change

Knowledge-based activities emerge when people, supported by information and communication technologies, interact in concerted efforts to co-produce (*i.e.* create and exchange) new knowledge. Typically, this involves three main elements: a significant number of a community’s members combine to produce and reproduce new knowledge (diffuse sources of innovation); the community creates a “public” space for exchanging and circulating the knowledge; new information and communication technologies are intensively used to codify and transmit the new knowledge.

The concept of public (or semi-public) spaces for knowledge circulation is complex. Such spaces can include areas in which exclusive property rights cannot be granted, either "constitutionally" (as in the case of open science) or within the framework of organisations especially designed for the purpose (research networks and consortia where partners share their knowledge) and markets whose *modi operandi* are conducive to efficient knowledge dissemination.

A knowledge-intensive community is one wherein a large proportion of members is involved in the production and reproduction of knowledge. Therefore, it is likely that such a community constitutes a public (or semi-public) space where codification and dissemination costs have been radically reduced by the pre-existence of commonly employed concepts and terminological conventions; the existence of the latter further facilitates information and communication technologies to enhance the circulation of new knowledge. In the next part, knowledge communities will be treated as one of the main sources of innovation for any sector of activity.

Knowledge-intensive communities and their "virtues"

In the modern world scientific communities may be regarded as the specialised social organisations most thoroughly committed to the knowledge-based production activity – if only because they are engaged in "the production of reliable knowledge by means of reliable knowledge". A majority of their members are, therefore motivated by the reward systems and social ethos reinforced by scientific community-specific institutions to disclose and share that knowledge (Dasgupta and David, 1994). Historically speaking, these scientific research communities, being concerned with the capture, storage, analysis, and integration of experimental and observational data, have been pioneers in the development and use of new information technologies. Communities of programmers engaged in creating and improving so-called "open source" software resemble "open science" research communities in many of these aspects, and, like them, are not able to extract economic revenues directly from the sale of the new knowledge and information-goods that they create. They must find collateral, or ancillary sources of support. The depth study for this project by von Hippel examines how open source projects operate as "horizontal networks" (see Box 1.1).

Some business-to-business communities, however, also have modes of operation that share some of the same features. For example, general research consortia are club-like organisations, devoted to some collective technological goals which the members regard as jointly beneficial, and best pursued in a cooperative manner.

Box 1.1. **How horizontal networks bring users into innovation: some key points from von Hippel's depth study***

Throughout history, innovation has relied on collaboration among different economic actors – in particular among producers, who can see that the collective production of knowledge and innovation (associated today with advancing collaborative technology) can sometimes yield a greater economic return than simple competition. However, it is also proving rational for users to participate in innovation, through collaborative networks.

A prime case of this phenomenon is "open source software" projects, in which users of software technology continuously adapt the product for their own use and freely reveal their innovations to others. While software design has been the most cited and obvious case, the phenomenon can be seen in a wide variety of cases, aided today by the ease of electronic communication with fellow-users which allows continuous "tinkering" across a network. One example of a technology whose design has been continuously advanced by user networks is high performance windsurfing, where a high proportion of boards manufactured today incorporate user-developed designs. User innovation is important among companies in a range of industries who are users of particular technologies.

User participation in design and free revealing of one's discoveries can make sense even in a world of economically rational competition. One reason for this is the advantage of being the first to market a new product line using a technology that becomes the norm. Another is that users can hold on to a certain degree of user know-how even when disseminating a new process, since information is "sticky" – *i.e.* costly to transfer – and thus can be most readily accessed at the sites of the users from whom it has originated. A number of other less tangible gains from free revealing include benefits to a company's reputation for being a pioneer of a technology, and the generalised benefits from an ethos of "reciprocity" in which openness with one's peers contains an element of altruism. User networks also tend to thrive under conditions in which it is difficult to patent or license innovations, because they are easy to imitate with something similar, and where it is difficult to keep an innovation secret.

Public policy can respond to the existence and advantages of user-led innovation, both by publicising its possibilities and by removing barriers to its introduction. This may include reconsidering how subsidies are given to manufacturers, to ensure that there is a level playing field in support for manufacturers and users when it comes to research, development and innovation.

* Full study paper: "Open Source Projects as Horizontal Innovation Networks – By and for Users", by Eric von Hippel, *www.oecd.org/edu/km/mappinginnovation*

Doctors represent another instance of communities, in this case communities of professional specialisation, that are undergoing a transition towards the higher frequency of peer-to-peer information transactions that is a key characteristic of the knowledge-based economy and, more generally, of the knowledge society. Many doctors now document their new clinical knowledge and make it available to others through easily accessible electronic databases. Other practitioners then can draw on or add to that pool of information, thus enhancing the advance of evidence-based medicine.

Curiously enough, however, teachers at the elementary and secondary level, on the other hand, do not fit the template of the modern knowledge-based communities, even though they make intensive use of knowledge. There may be a massive amount of innovation going on as individual instructors strive to find solutions to their teaching problems, but, perhaps because those problems involve working with "unstandardised materials", *i.e.* their students, relatively few of those pedagogical innovations are passed on to, and shared by the rest of the community (Hargreaves, 2000).

Communities characterised by all three of the aforementioned components (extensive knowledge creation and reproduction, mechanisms for exchanging and disseminating the resulting knowledge and an intensive use of new information technologies) tend to be fundamentally geared to knowledge-driven production. As such, they display a certain number of "virtues":

- knowledge enhancement is boosted by a host of opportunities for recombination, transposition and synergy;
- a large share of the knowledge base is codified, which leads to greater storage and communication capacity and makes it possible to develop new cognitive approaches;
- quality control is guaranteed because members can each reproduce, test and criticise new knowledge;
- static efficiency is, as a rule, reinforced, meaning that because everyone has access to the knowledge produced, the same items will not end up being reinvented (while new knowledge can benefit from strong collective focus, collaborative experimentation and enhancement efforts);
- learning productivity is made greater by the fact that an individual can "learn to learn" through reproducing the knowledge of others;
- opportunities have emerged for the spatial reorganisation of activities and the creation of virtual communities as it has become less expensive to move knowledge than people.

Is there an optimum size of knowledge-intensive community? From an empirical point of view, sizes will be seen to vary greatly between the global community of high energy particle physicists (comprising several thousand members) and a tiny community of aeronautical engineers working on a particular problem in airfoil design, or consortia among teams of molecular geneticists seeking to identify and locate the gene for a heritable form of breast cancer. The potential for producing and reproducing knowledge will become greater as a community expands; but then so will the costs of data search, the risk of congestion and anonymity amongst members, which can, in turn, represent a source of acute problems of trust. Optimum size may be said to vary as data search and filtering technologies improve and new trust-building mechanisms are perfected (see below). But it also depends on the nature of exchanges (geared merely to accessing a knowledge base or stemming from intensive interactivity within the framework of a research project).

Knowledge communities as agents of economic change

Most knowledge communities cut across the boundaries of conventional organisations (businesses, research centres, public and government agencies, etc.) and members of the former are at the same time employed by the latter. So, the development of the knowledge economy has seen, *inter alia,* conventional organisations infiltrated by individuals whose continuing attachment to an "external" knowledge community makes them all the more valuable to the organisations that harbour them as regular employees. Examples of this phenomenon from the world of business include engineers belonging to different firms who exchange knowledge and "trade secrets" within the framework of a network operating by the rules of reciprocity (von Hippel, 1988b); scientists employed by large pharmaceutical companies who are encouraged to publish in scientific journals and retain strong links with their university-based scientific counterparts (Cockburn *et al.*, 1999); cooperative projects among users of the same technology (*e.g.* software) who expect to make use of the improved technology in the work as employees of different, and even rival companies. By penetrating conventional organisations, these communities become agents of change for their industry, and, indeed, for the economy as a whole.

In every such situation, however, there is always a danger of problems arising due to conflicts between private-sector companies that regard new knowledge as their exclusive property, and knowledge communities to whom sharing knowledge is their *raison d'être.* The knowledge community is a fragile structure in that it is based on informal rules (reciprocity, disclosure). So it can rapidly disintegrate when their members lose the ability or the dedication to follow those rules, and, instead seek to further their individual interests through non-cooperative action in the realm of markets.

1.5. A few unanswered questions

The foregoing formulation of a definition and analytical approach to the notion of "knowledge-based activities" still leaves a good many quite basic questions to be answered concerning the workings of the evolving knowledge-based economy.

Does the knowledge-based economy demand specific skills and abilities?

Are "new skills and abilities" required for integration into today's knowledge economy? If so, what are they? Are they really as new as some might like to make out? Beyond the levels of proficiency needed for the use of information technologies, there do appear to be a number of set requirements: teamwork, communication and learning skills. But these sorts of "soft skills" can hardly be described as new. Indeed, though sidelined during the age of Fordism, they have always, throughout history, been crucial to the development and well-being of individuals in the world of work.

Many experts underscore the importance of generic learning abilities (learning to learn, knowing what we do not know) and of being aware of the main forms of heuristic bias that can distort the power of reasoning (this can happen when too much importance is attached to the latest information or too little attention is devoted to the size of sample selected to assess information). It is better to have a firm command of such abilities, they say, than to be able to master a specific repertoire of technical skills. The need to keep up with incessant change is essentially what drives employees to develop new kinds of skills and abilities. These go beyond the constant updating of technical knowledge, for they also pertain to the capacity to understand and anticipate change.

Returning market work to the home?

Given how efficiently knowledge can travel when reduced to information, and the fact that the costs involved in moving people are still so high (and even rising with the growth in size of urban areas), one may well have grounds for believing that increasing numbers of people are going to be working at home now that the technological capacity is available for knowledge-sharing, remote access and teamwork, and organising and coordinating tasks over wide areas. Does this herald the end of geography or, at the very least, of the influence of geographical distance over how activities are organised? Clearly, the influence of geographical distance is waning. Many different kinds of transactions now take place within the framework of location strategies "unconstrained by distance". And many customers have not the slightest idea where (geographically speaking) their transaction is being processed.

But whether or not this marks a trend of work returning to the home is rather less clear. Historical perspectives are still too sketchy to ascertain whether there really is "some tendency for the pendulum to start swinging back" (Mokyr, 2000), thus ending the centuries-long development of a factory system that has compelled workers in industry then services, trade and education to commute to work. The costs involved, though impossible to quantify, have certainly been huge. Cairncross (1997) suggests that in "half a century's time it may well seem extraordinary that millions of people once trooped from one building (their home) to another (their office) each morning, only to reverse the procedure each evening … Commuting wastes time and building capacity. One building – the home – stands empty all day; another – the office – stands empty all night. All this might strike our grandchildren as bizarre". Mokyr (2000) makes a sound case for considering some development of a home-production economy in light of the fact that it costs less to transport knowledge than people. Such developments, however, are likely to continue being impeded by all manner of apathy for some time to come. Which leaves much to be done as regards the redesigning of space in line with the opportunities offered by the knowledge economy.

Furthermore, many activities cannot be coordinated by virtual means alone. The emulation and spontaneity generated by physical presence and social groupings often remain crucial. Likewise, direct face-to-face exchanges are important when they enable other forms of sensory perception to be stimulated apart from those used within the framework of electronic interaction. For many individuals, it is the personal interactions of the workplace, the stimulus provided by a change in environment from one's domestic habitat, that makes work enjoyable; futuristic scenarios depicting the joys of tele-working from one's home-office often are expressions of solitary authors, impatient with the intrusions of the world and people about them.

On the whole, individuals now have far more room to choose between working at home (and cutting commuting costs) and travelling to the collective workplace (to benefit from the advantages of interacting with a "real" group), but the question remains as to the extent that this option will prove attractive.

1.6. The challenges

The profound transformations that we have been examining are neither automatic and inevitable, nor will the results of the changes underway necessarily turn out to be universally beneficial. It is therefore important now to consider six major issues that our societies need to address in order to ensure a fuller realisation of the potentials of the knowledge economy.

Access to information and to knowledge bases

Our community-based approach has the virtue of showing that access to the knowledge economy is still highly limited and that there are great disparities between countries and social groups.

Clearly, the frequently distinction drawn between "information society 'haves' and 'have-nots'" is overly simplified, as is the notion that there has emerged a "digital divide" that can and should be overcome by providing universal technical access to the Internet. Telecommunications access undoubtedly is a relevant consideration, given that more than two-thirds of the world's people today do not have the advantage of simple telephone connections, let alone computers and links to Internet service providers. Yet, the more difficult and in a sense more fundamental problems are not simply those of providing greater technological access to information streams. Rather, they involve furnishing people with the cognitive capacities and intellectual frameworks than enable humans to interpret, select and utilise information in ways that augment their capabilities to control and enhance the material circumstances and qualities of their existence.

One may say, then, that one of the respects in which "knowledge is power" reflects the fact that knowledge access is essential for meaningful information access. The relationship between human knowledge and information is reflexive, however; the formation of an individual's knowledge beyond the acquisition of understandings derived from personal experience is enormously abetted by receiving interpretable (decodable) information that encapsulates the shared learning of others. To put the point plainly, the nature of the content that is readily available for distribution is critically important. Access to channels of communication that are transmitting information of certain, capability-building kinds can play an instrumental part in accelerating the acquisition of the human cognitive skills that will impart enhanced relevance and greater value (utility) to the other information streams which also may be carried through those same channels.

Returning to the simpler issue of providing universal telecommunications access, for the moment, it is important to acknowledge how large a gap exists between reality and the evocative idea that because we all share the planet, humankind belong to "a global village" (UNDP, 1999). On the one hand, information infrastructure in some countries is so poor that "planet Internet" would appear to belong to altogether another galaxy. As many as 133 developing countries have asked the United Nations to maintain radio stations and other traditional media as a means of disseminating information, because use of the Internet alone would exclude many people from access to information flows.

Participation in knowledge-based economies, on the other hand, stems from intangible-capital investments in educational effort on the part of teachers and students, efforts directed to forming the basic skills and abilities (reading and writing) that text-based cultures require. Claims that a technological leap would enable a society to bypass certain stages in the development of knowledge infrastructures should be taken with a pinch of salt. Could e-books ever compensate for the lack of paper text-books for elementary school instruction? Can a civilisation rid itself of the disabilities of illiteracy through the widespread application of audio-visual media? Hardly. Post-literacy does not mean a return to illiteracy. It may be enjoyable and in some instances highly efficient for people to exchange information imparted by pictures, but, until a richer and standardised pictorial vocabulary is created, increasing reliance upon non-textual communications eventually will restrict the cognitive progress produced by more complex (codified) representations of knowledge.

That said, our community-based approach does provide a good many pointers and grounds for hope. Some scientific communities in the developing world are close to meeting the conditions to be able to participate more fully in the discovery and creation of new knowledge, rather than remaining trapped behind the frontiers of research and therefore unable to direct its advance toward the solutions of problems that have pressing relevance in their own societies. In their case, then, the problem really is one of becoming extensively equipped with high-quality information infrastructures of a sort that the researchers (many of whom trained abroad) already are capable of using.

Some of the problems of access to the large-scale and very costly research facilities in the natural sciences – of a sort that only the economically developed countries can afford, often through cooperative undertakings – now may be overcome by means of high-speed telecommunications. The latter permit remote access to observational instruments and mass data-transport for subsequent analysis, and the cost of providing the necessary bandwidth typically is much lower than that of constructing the facilities, even if the technical capability to build these existed in the developing country.

While "moving the data" is thus part of the solution, the international movement of scientific personnel gives rise to some significant problems for the developing countries. These are the losses of research and future teaching talent that may occur so-called "scientific and engineering brain drains". As long as the viability of the developed countries' systems continues to rely upon talented students abroad as the means of overcoming shortages of young people seeking advanced scientific training, they will pursue selectively liberal immigration policies that developing-country scientists find hard to resist; and communities will not be formed in their home land. Some authors call for the deployment of knowledge networks that involve the return of scientists and engineers (*e.g.* from California to Taiwan or certain parts of India). According to this "brain circulation" model, the latter return home highly trained and imbued with the entrepreneurial spirit of Silicon Valley. But it gives rise to other such problems as the isolation of the scientific elite from the rest of the population and the propagation of a single socio-economic model (Saxenian, 2001).

The development of dynamic scientific communities does, of course, hinge on a number of other factors. But all the means are in place to bring an end to the "relentless pursuit of instruments of knowledge" for scientists working in developing countries. Other professional communities – doctors, teachers, urban planners and architects – also represent focal points where the key components of the knowledge-based community should gradually be deployed.

Uneven development of knowledge from one sector to the next

Unequal access to pertinent knowledge bases may well constitute an important condition underlying perceptible differences in the success with which different areas of endeavour are pursued within the same society, and the pace at which productivity advances in different sectors of the economy during a given historical epoch. In the 19th century, for example, even in the more developed high income economies, the improvement of agricultural productivity lagged behind that in industry in good part because the relevant knowledge base in plant and animal biology and soil chemistry was comparatively narrower, and less dynamic, than was the case in mechanics and inorganic chemistry. That situation was largely transformed by the second half of the 20th century, as is testified to by the successes of "the Green Revolution" brought by new plant varieties, and the acceleration of agricultural productivity growth rates in the advanced economies to parity with those in their manufacturing sectors.

Today it remains astonishing to observe the contrast between fields of economic activity where improvements in practice are closely reflecting rapid advances in human knowledge – such as is the case for information technologies, transportation, and certain areas of medical care (surgery and drug therapy) – and other areas where the state of knowledge appears to be far more constraining. Do people today know how to teach, plan cities, avoid the ravages of war, or perform string quartets any better than they did in the 19th century? Probably not to any noticeable extent. The fact is that knowledge is not being developed to the same degree in every sector.

In some measure this is attributable to the failure of mechanisms that would otherwise properly gauge the intensity of each of the items forming the array of society's wants, in the way that markets gauge the intensity of demands for the array of privately consumed commodities; thereby generating price signals which stimulate profit-motivated efforts to satisfy those wants. The combatants in a military conflict generate demands for weapons, to which arms merchants hasten to respond; the civilian populations that, as a result are likely to be "collaterally damaged" are not so readily able to generate "a market for inoperable weapons". Analogously, albeit less dramatically, the same point is made by observing that pharmaceutical companies respond to the large market demand for new drugs to treat ulcers and hypertension, rather than investing R&D on improving the availability of drugs for the victims of malaria and other tropical diseases that ravage poor countries.

Nevertheless, differences in the ability to focus demand do not provide a complete explanation. It is equally important to acknowledge that the uneven state of the accessible knowledge may arise from the fact that the capabilities for supply to respond to perceived wants are not everywhere the same (Foray and Hargreaves, 2003). The sectors where knowledge creation has occurred at an extremely rapid pace are those in which the interrelationships between science and technology are especially close and intense. These are the sectors capable of carrying out controlled experiments and thoroughly testing results while maintaining constant liaison and feedback between the various stages of experimentation and application. Besides, technological advances generate better scientific instruments, which in turn help to improve experimentation methods. The interlinkages between "science-enlightened technology" and "technology-equipped science" provide the basis for the rapid development of knowledge in some areas. It is a model that involves heavy investment in off-line experimental research activities and large-scale knowledge codification so that interactions between science and technology can be sustained by a standardised and systematic knowledge system.

Many sectors visibly fail to meet these conditions for rapid progress. In the field of education, for instance, science does not much "enlighten" the art of teaching. It can hardly be said to play a very strong role as a factor enabling the direct production of systematic knowledge which translates into "programmes that work" in the classroom and lecture theatre. Education is not a field that lends itself well to experimentation: what works with a pilot school may prove hard to replicate elsewhere. Part of the problem is that experimental approaches are impossible to describe in precise enough detail to be sure that they really are being replicated (Nelson, 2000). Education also constitutes a realm where knowledge is little codified. There are fewer equivalents in teaching to the kinds of reference books and documents used by doctors, lawyers or engineers. So young teachers begin their careers without the help of those “sets of codified instructions”. As a rule, the profession of teaching is not organised to keep practitioners informed of alternative approaches and solutions tested by others; instead they proceed by intuition and imitation of recognised practices in the repertoire of “master teachers”. There are only weakly developed mechanisms whereby communities of educational practitioners collectively can capture and benefit from the individual discoveries made by their members. Opportunities for regular knowledge exchanges between educational researchers and teachers are few and far between (Hargreaves, 1999).

A good number of sectors not benefiting from the “science-enlightened technology” model thus find themselves confronted by the question of how they can enhance knowledge at similar speeds to the science-based sectors. Instead of attempting to export that model to sectors where it is ill-suited, one would be better off devising a role for science in contexts where the bulk of innovation stems from practical experience; a role geared not just to supplying “tools that work”, but to developing a methodology for documenting, assessing and promoting practice-based innovations.

The success of the “science-enlightened technology” model has obscured the fact that there are other ways in which science can interrelate with technology; and that developing them can help to improve the advancement of knowledge in some sectors.

To protect intellectual property rights or the public domain of knowledge?

The past two decades have witnessed growing efforts to assert and enforce intellectual property rights over scientific and technological knowledge through the use of patents, copyrights, and other, more novel forms of legal protection. These developments have coincided with two other trends that, similarly, have tended to expand the sphere of private control over access to knowledge, at the expense of the public knowledge domain.

One trend has been the rising tide of patenting activity by universities, especially in the areas of bio-technology, pharmaceuticals, medical devices and software. This movement started in the United States, where it received impetus under the 1980 Bayh-Dole Act that permitted patent applications to be filed for discoveries and inventions issuing from research projects that were funded by the federal government, but has since spread internationally, being reinforced by the efforts in other countries to foster closer research collaboration between universities and public research institutes, on the one hand, and private industry on the other.

The other trend has seen a concerted effort by all parties to secure copyright protection for the electronic reproduction and distribution of information, in part to exploit the opportunities created by electronic publishing, and in part to protect existing copyright assets from the competition that would be posed by very cheap reproduction of information in digital form over electronic networks.

The sudden wild passion for private property in the realm of knowledge creation has given rise to a rather paradoxical situation (Foray, 1999). The technological conditions (codification and low-cost transmission) may be right for individuals to be able to enjoy instant and unfettered access to new knowledge, but a proliferation of intellectual property rights prevent access to such knowledge in hitherto protected areas (basic research in general, life sciences, software). People are striving to create artificial shortages in fields where abundance naturally prevails, thus giving rise to an enormous amount of waste.

To understand this, one has to realise that knowledge is not like any other kind of property. Intellectual property cannot be placed on an equal footing to physical property for the simple reason that knowledge and information possess a specific characteristic that economists refer to as “non-rivalry in use”. This is not true of physical property: if Marie eats the last piece of bread and butter in the kitchen, Camille cannot eat it too. The allocation of property rights in this case clearly serves to improve the functioning of a decentralised market economy.

When Théo, on the other hand, is listening to a piece of music, modern reproduction and transmission technologies will allow Quentin, Manon and millions of others to listen to the same piece without generating extra costs. In this case, if the creation of intellectual property rights excludes some potential users, there is waste. Some people’s desires will remain unsatisfied even though they could have been assuaged for nothing (or next to nothing). Waste is a powerful argument that can be applied in an endless variety of ways in such areas as free access to certain patented medicines, the free reproduction of encrypted musical programmes on the Internet or use for research purposes of privately owned digital databases.

Producers of ideas and creators of music do, of course, respond to incentives. If they had no right over their works, they would create less or nothing at all. So there really is room for intellectual property rights. But there is no easy solution to this economic problem and answers to the questions raised (are rights a must and, if so, what form should they take?) will vary from one case, area or situation to the next. What is clear above all else is that the creation of rights governing ownership of knowledge, itself a source of new knowledge (research tools, databases, generic knowledge), creates an enormous amount of waste by blocking access not just to a consumer good (a poem or musical programme) but to factors of production. Collective knowledge enhancement is prevented by the fact that what is being passed around cannot be enriched, commented upon and recombined by others. Popular wisdom maintains that "good fences make good neighbours". This may apply in the case of two farmers with adjacent fields – one growing crops and the other grazing cattle – or gold diggers excavating neighbouring concessions. But unlike land, forage or other kinds of exhaustible resources, knowledge is not depleted by use for consumption; data-sets are not subject to being "over-grazed", but instead are likely to be enriched and rendered more accurate the more that researchers are allowed to comb through them (David, 2001).

This amounts to a very serious problem; a problem of access to scientific knowledge for developing countries; of the general dynamics of knowledge being severely hindered; of every individual's right to have access to the latest breakthroughs in key areas such as health and education.

A delicate balance may have been established in sectors where services have a profound effect on "well-being" (health, education). The right to health and education appears to have the "strength" to help establish ways to regulate private appropriation (see Chapter 3 about these issues as concerning educational methods and materials).

New problems of trust?

Fraudulent behaviour, forgery and pretence have obviously not been spawned all of a sudden by the virtual world. Questions concerning the original and the copy, not to mention the evaluation of goods that are the object of commercial transactions, have given rise to the problem of trust and have highlighted how crucial trust-building mechanisms are to the functioning of markets and communities since the beginning of time. But the development of virtual relations has given the trust issue a new edge. What is at stake here is the entire range of mechanisms that will facilitate interpersonal and inter-organisational transactions, given the new conditions for knowledge transactions and exchanges: increasing specialisation, increasingly asymmetrical distribution of information and assessment capabilities, ever-greater anonymity among interlocutors and ever-more opportunities for forgery of identity. Clearly, new methods need to be devised to "certify" the knowledge circulating on the Internet within a context where inputs are no longer subject to control (unlike the knowledge disseminated by scientific journals, for example, whose quality and reliability are validated through the peer review process).

A society bereft of memory

Today's younger generations might never experience the emotions aroused on rediscovering old toys or books in the attic and picking them up to find that they still work. Future machines may never be able to bring back to life the equivalent of our elders' wooden horses and toy soldiers: the Playstation, earlier versions of which are already impossible to use on the latest computers. Our societies are confronted by an almost paradoxical situation whereby we have never before had such powerful storage and memorisation technologies at our disposal, yet memory itself appears to be in danger. Two problems are beginning to emerge.

First, with information technologies, we are not saving documents but sets of instructions that need to be interpreted and managed by the right hardware and software. So any lack of attention paid to the complementary components of a codified knowledge system (continuity of languages, keeping programmes that enable access to older files) runs the risk of irremediably altering society's overall memory.

Second, given the exponential growth of all manner of documents, does it all really need to be kept? If not, then what does? On what medium (electronic, paper)? The unit costs of short-term storage and data retrieval may have fallen, but significant problems remain with respect to memorising, filing and accessing old documents. The new electronic media for storage are not so stable, indeed, they are unstable in comparison with the low-sulfite rag paper on which good books have long been printed. Furthermore, the artificial language used to encode information for computer processing also is comparatively less stable, in that it is more likely to suddenly become obsolete, requiring the corpus of stored information to be periodically "migrated" to a new code that new programs are able to read. This has made "storage" of information in the digital age less a matter of archiving than a process of recurring renewal, a cultural task for which literate societies turns out not to be well-prepared.

Fragmented knowledge: how can it be put back together again?

There is a natural tendency for knowledge to fragment as it becomes subject to more in-depth division and dispersion. The division of knowledge stems from divisions of labour and increasing specialisation. Its dispersion is the product of increasingly diffuse sources of innovation. The result is an extremely fragmented knowledge base, which makes it difficult to form a broad and integrated view of things. This can have disastrous consequences. At the level of global policy making, knowledge that can help resolve a particular problem may exist without being "visible". It can go unnoticed by the decision maker. Knowledge of the greenhouse effect, for instance, has been in the public domain since 1886 thanks to the study by Svente Arrenhuis, but failed to capture the attention of the political system for another hundred years. There is a big difference between the existence of knowledge in some place or the other and its availability to the right people in the right place at the right time. It amounts to a matter of knowing how to integrate and organise fragmented, scattered and thinly-spread knowledge.

The famous economist, Alfred Marshall, raised basically the same question, albeit with respect to industrial activities: how can one organise and coordinate highly specialised activities within a context marked by an extreme social division of labour? The answer, according to Marshall, lay in two main factors: a reduction in transport costs and local concentrations of activity clusters, with each locality creating the right conditions for integrating knowledge.

So the whole question revolves around the capacity of the new information technologies to enable better integration of knowledge through helping bring down the cost of transporting it and paving the way for local concentrations of virtual activities.

The new technologies, under certain conditions clearly do favour the low-cost transmission of knowledge and the creation of virtual communities. But the maintenance of human organisations in which incompletely codified knowledge resides poses a variety of socially and politically delicate challenges, involving the establishment of procedural authority to decide contested cognitive questions and stabilise the knowledge held by the community, as well as to recruit new members and inculcate in them the cooperative mores that suppress destructive opportunistic behaviours. Evidently, managing a social repository of knowledge is not the same thing as managing a library or an archive. Yet, much of the history of civilisation, from the dawn of literacy onwards, has focused attention and physical resources upon the evolutionary elaboration of archiving techniques and brought a corresponding waning of systematic commitment of investment in alternative modes of maintaining the continuity of memory in dynamic communities.

That is not the only problem, however: some researchers argue that the use of powerful communication technologies such as the Internet may promote uniformity to the detriment of diversity (van Alstyne and Brynjolfsson, 1996). The time spent in on-line exchanges with members of one's own, pre-selected community leaves less time available for actual encounters with a wide-ranging variety of people: if a physicist is enabled to concentrate upon exchanging email and electronic pre-prints with other physicists around the world who are working in his/her specialised subject area – as indeed researchers today generally are – they are likely to devote less time, and be less receptive to new ways of looking at the world to which they would be exposed by chance meetings, and lunch-time conversations with colleagues who work in other disciplinary fields. Facilitating the voluntary construction of highly homogeneous social networks of scientific (or other, say, political) communication therefore allows individuals to filter the potentially overwhelming flow of information. But the result may be the tendency of over-filtering, which eliminates the diversity of knowledge that circulates, and thus diminishes the frequency of radically new ideas. In this regard, even a journey through the stacks of a real library can be more fruitful than a trip through today's distributed virtual archives, because it seems difficult to use the available "search engines" to efficiently emulate the mixture of predictable and surprising discoveries that typically result from a physical shelf-search of an extensive library collection. New technologies are not automatically going to resolve the issue of knowledge integration. What really needs to be done is to establish and develop interdisciplinary communities made up of a heterogeneous range of members. In such cases, the sound "Marshallian" properties of information technologies really can serve to support the integration of knowledge.

The above arguments demonstrate that it is important to integrate the use of new knowledge technologies with that of old ones. Box 1.2 demonstrates that the latter are by no means redundant. Indeed, the future development of libraries, archives and museum collections will be important to addressing a range of issues raised in this chapter, including the public sharing of intellectual property, the retention and de-fragmentation of knowledge and the building of trust in the quality of information.

From the knowledge-based economy to the knowledge-based society

The knowledge economy's growth into the knowledge society hinges on the proliferation of knowledge-intensive communities. These communities are basically linked to scientific, technical and some business professions or projects. As has been said, they are characterised by their strong knowledge production and reproduction capabilities, a public or semi-public space for learning and exchange and, the intensive use of information technologies. To function effectively, they must have overcome many, if not all of the challenges that this review has identified. Only when increasing numbers of communities displaying those very characteristics are formed across a wide array of cognitive fields, when professional experts, ordinary users of information, and uninitiated students are brought together by their shared interest in a given subject, will "the knowledge society" become a reality rather than a vision of a possible future.

Box 1.2. **Old and new repositories of knowledge – the enduring role of libraries, archives and museum collections in the Internet age: some key points from Hedstrom and King's depth study***

Traditional knowledge institutions are not obsolete, but need to focus on where they have a distinctive role, especially in supplying public goods that are not replicated on the Web.

What is the significance and role of the three big institutions traditionally devoted to knowledge organisation and accumulation – libraries, archives and museums (LAM) – in the knowledge age? Hedstrom and King refute the view that new ICTs will remove the needs for such institutions in the future.

The LAM are the oldest examples of knowledge organisations. Societies have built and sustained institutions to collect, organise, preserve and provide access to knowledge-bearing objects for more than two millennia, but today face a period of deep uncertainty. The advent of the Internet has both re-ignited naïve notions of a single universal collection of all knowledge while also amplifying competing sources for information access in ways hitherto impossible. Through the Web, the LAM are facing serious competition from alternative service providers, possibly for the first time in their history. The Web might be thought of as a global substitute for the LAM because it allows a globally distributed population to publish and access information easily.

However, the Web is weak on some traditional strengths of the LAM, such as legitimation and authentication of information, careful selection, and the persistence and structure provided for information access. Nevertheless, recent surveys show the dramatic decrease in the use of traditional libraries by students vis-à-vis the use of netLibrary. The on-line bookseller, Amazon.com, has a kind of library catalog listing several million titles. Amazon's collection probably compares well with major research libraries in the number of titles available.

The advent of commercial services such as Amazon causes an important shift in the institutional function of the LAM. For centuries, the LAM have operated as a kind of public good supported by a patronage structure of universities, governments, and philanthropy. This arrangement never required a very robust means for judging their economic value. Hedstrom and King illustrate that the method of measurement of the contribution of the LAM to social welfare was very crude. This was fine as long as the patrons accepted the idea that the LAM were an important public good and they had to be funded at the appropriate level. The rise of the Amazon model is challenging this way of estimating costs and benefits.

This transformation should, however, not be guided by the (wrong) idea that the LAM and the Web can substitute for one another. The market cannot provide all of the services of the LAM and still remain profitable. Amazon.com for example uses the LAM infrastructure for cataloguing data (the cataloguing-in-Publication initiative in the US has a quality control procedure which is managed by the Library of Congress). Also, Amazon.com has no mission to maintain a collection of out-of-print and obsolete materials in anticipation of some potential demand long in the future. In a sense, the LAM, the Web and market forces are complementary in four key areas: access, information quality and integration, social memory, and information property. The complementary nature of the traditional LAM and the emerging Web is explored in this depth study for each of these areas, providing a strong rationale for the preservation and development of the LAM as a public good:

- access: while ICTs create opportunities to facilitate access to important social information of any kind (healthcare, employment opportunities, on line forum, etc.), libraries still serve as equalisers in disparities of access to information by providing free access to materials that individuals cannot afford to purchase. Another vital complementarity in terms of access is in the co-location of physical collections (in the museum) and the information necessary to learn from them;

- information quality assurance: the Web is easy to use and provide fast access to a vast amount of information. It is, however, inadequate for teaching and research where definitive and high qualities of information resources are instrumental for critical analysis and innovation. The complementary nature of the traditional LAM and the Web is illustrated by the role of LAM professionals who are providing LAM-like services on the Web;

- social memory: an essential function of the LAM is the accumulation and preservation of knowledge that might someday be of vital importance. The LAM are the most important form of long-term social memory; a function that the Web cannot take up. Indeed one Web feature is the massive and routine loss of information; and

- information property: while some trends towards copyright restrictions on digital content have become so draconian that they are counter-productive to innovation and knowledge generation, one fundamental social function of the LAM is to preserve large domain of free access to knowledge. Of course, the Web is not just the realm of propertisation of knowledge. It is an area in which many social experimentations are possible and actually carried out to generate alternative distribution and purchasing mechanism. SPARC is an example of an alliance of more than 200 universities which has been set up to develop a new model of scholarly communication, capable to offer a competitive alternative to current high-priced commercial journals and digital aggregations.

* Full study paper: “On the LAM: Library, Archive and Museum Collections in the Creation and Maintenance of Knowledge Communities”, by Margaret Hedstrom and John Leslie King, *www.oecd.org/edu/km/mappinginnovation*

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CHAPTER 2
THE INNOVATION TANK AND THE FOUR PUMPS: MAPPING INNOVATION IN THE EDUCATION SECTOR

This chapter identifies, with reference to depth studies documented in this project, four key factors which are becoming important drivers of innovation in the economy generally, and later discusses how such factors could play a role in educational innovation. In doing so, it uses the metaphor of "the innovation tank and the four pumps": the pumps are used to deliver fuel (innovation) to the car, filled from a tank. The tank represents innovative *potential* within a sector; the pump a means of delivering the innovative fuel to the engine of innovation – its application in practice. In describing the various pumps needed to deliver an innovative capacity, this chapter looks at the *sources* of innovation, rather than at what specific *type* of innovation is needed in education. This chapter starts by describing how each of the four pumps works, suggesting some stylised facts about innovation processes. It then discusses how these insights might be most fruitfully translated and combined in the education sector.

2.1. Introduction

Education has always by definition been concerned with knowledge, yet knowledge has played an ambiguous and imperfect role in improving the effectiveness of education systems. In particular, there has not been a straightforward translation of educational research into practice, applying what is known about effective educational approaches directly into classrooms and lecture halls. A simple linear relationship between scientifically derived knowledge and its application has proven appropriate neither in the making of education policy (OECD, 1996) nor in the production, mediation and use of knowledge in educational practice (OECD, 2000).

In this context, scientific advance has a disputed role as an engine of educational innovation. Some of those currently involved with educational improvement are putting increased emphasis on implementing in practice those strategies that have been shown through formal evidence to work best – an "evidence-based" strategy with close parallels in health care. Others, studying innovation in various sectors, look more to organisations and the people who work in them to develop informal understandings of what works: they emphasise "tacit" knowledge that cannot be fully "codified" into explicit methods that can be shown to produce superior results. Competing theories of innovation highlight, for example, the importance of user networks rather than external scientific knowledge in driving the advance in know-how, or the vital role of the application of information and communication technologies.

However, this chapter argues that it is misguided to look for a single source driving innovation in today's knowledge economies. The experience of a range of sectors suggests that innovation depends on multiple factors involving the development of both tacit and explicit knowledge. Important influences include not only well established elements such as the strength of scientific R&D but also newer ones like the dissemination of knowledge through electronic networks.

Inside the tank

The metaphor used in this discussion envisages a "tank" of innovative potential whose fuel is released by "pumps" which are processes of innovation. This raises an interesting question about whether innovative potential has an independent existence, separate from the means of discovering and delivering it. In some cases it clearly does. For example, the potential of a circular structure rotating on an axle, as an efficient means of conveying vehicles, existed in principle before it was discovered with the invention of the wheel. On the other hand, an effective classroom teaching method, developed by teachers in collaboration with each other and with students, is a social fabrication that only in a very theoretical sense existed "in principle" before it was developed. Nevertheless, it is useful to think of a tank of innovative potential, in discussing certain practices or techniques that can work, and which are accessible if they can be discovered by one of several means of innovation.

The four innovation pumps are:

- *science-based* innovation. Science plays an unquestionable role in advancing knowledge. However although it can produce rapid progress in knowledge, its findings are often generalised and applied only slowly.
- *collaboration* among users and/or doers. New actors are becoming engaged in innovation processes, develop collaborative modes of knowledge generation, and this creates new opportunities.
- *modular structures,* each with freedom to innovate, yet joined together in a whole innovative system. This devolved character of innovation in

complex technological systems creates new needs for co-ordination and certification.

- *information and communication technologies*, harnessed effectively as an instrument of innovation, can be a powerful trigger for transforming activities.

These forces of innovation can be observed in action across a broad set of sectors in our depth studies, ranging from software to pharmaceuticals, basic science, microelectronics and health care systems. Different sectoral experiences can be applied to varying degrees and in different ways in other sectors, such as education. This does not imply perfect generalisability of all experiences. Although for example the microelectronics industry provides an excellent example of all four pumps in action, the education sector has its own particular knowledge processes and institutional relationships that determine the uses that each pump may serve. The important thing for policy makers, though, is not to neglect the potential usefulness of any of these pumps as four prime sources of innovation in the knowledge economy.

2.2. The first pump: science-based innovation

Scientific knowledge potentially contributes to creating new or improving existing products, services, processes and organisations. In education as elsewhere there is scope for building and expanding of a scientific knowledge base through experimental R&D. But what experiences elsewhere in the knowledge economy tell us about the role of science?

A scientific approach contributes to innovation in three different ways:

- It provides a more systematic and effective base for discovery and innovation.
- It allows for better control (quality, impact, regulation) of the new products and processes introduced.
- Finally, it may be at the origin of entirely new products or processes.

Why does science contribute to innovation?

A scientific approach is important because it makes it possible (in most cases) to conceive and carry out well defined and controlled experimental probes of possible ways to improve technological performance, and to get relatively sharp and quick feedback on the results (Nelson, 1999). Well-defined and controlled experimental probes require isolation of the technology from its surroundings. Experimentation is often carried out using simplified versions (models) of the object to be tested and of its environment. Using a model in experimentation is a way of controlling some aspects of reality that would affect the experiment, in order to simplify analysis of the results. The ability to perform exploratory activities that would not otherwise be possible in real life is a key factor supporting rapid knowledge advances.

In an increasing number of sectors, the possibility to carry out "experimentation" generates a large scientific knowledge-base. Some industrial sectors have for a long time used scientific approaches to create knowledge (electricity, chemicals). Yet most major technological breakthroughs were not directly based on science. Rather, science plays a slowly expanding role by *illuminating* technology to fuel innovation, in sectors where pure research rarely or never leads directly to innovation.

Sectoral cases

The growing influence of the scientific approach has been particularly significant in industrial sectors. Drug discovery is a good example of a domain which has recently been characterised by a shift from a random approach through large scale screening towards a more science guided approach relying on knowledge of the biological basis of a disease to frame a research strategy. Another recent case is innovation in the development of adhesives, which has been fuelled by the use of scientific knowledge of the transition properties of certain materials, which provides a theoretical base for more effective and systematic R&D.

At the same time, this growing influence is also quite clear in people-centred professions. In the health and pharmaceutical sector, scientific methods such as randomised controlled trial are used to compare a new drug with the best existing therapy. The accepted "gold standard" of evidence in this kind of approach is "double blind" testing of a new drug, in which patients are randomly assigned to groups receiving the new treatment and an existing one or a placebo, without either themselves or the physician knowing who is in which group. In social and educational research, randomised controlled trial or randomised field trial offers great potential to generate scientific knowledge and robust evidence on a broad range of topics (Fitz-Gibbon, 2001).

Such scientific approaches seem constantly to cover new ground, even in sectors that appear to be, a priori, the least suited to them. Across a heterogeneous array of contexts (from drug discovery to adhesive products, therapeutic testing and education), scientific knowledge bases of direct use to innovation are being established. The idea is not to rehabilitate the old linear, so-called "science push" innovation model, but to understand and exploit all aspects of knowledge systems where there is greatest potential for knowledge advances to contribute to productivity and effectiveness. Scientific research helps speed up change in response to market signals and to the emergence of certain social demands.

Two forms of connection

The connection of scientific research to innovation has two distinct forms. First, scientific knowledge creation at some basic research stage allows more effective innovative research in industries and services that escapes from much longer and usually much more expensive and uncertain process of cut and try ("empiricism"). Second, we note the appearance within the firm and other organisations of scientific investigation tools. Hence, the ability to organise rapidly a large number of experiments based on simulation is revolutionising design and development work. Automotive companies are currently advancing the performance of sophisticated safety systems that measure a passenger's position, weight and height to adjust the force and speed at which airbags deploy. The availability of fast and inexpensive simulation enables massive and rapid experimentation necessary to develop such complex safety devices (Thomke, 2001).

These developments all point to the idea that a wide range of research problems warrants an effort at collecting scientific data, and that appropriate forms of experimentation are necessary and most often possible. One of the features of the knowledge economy is that many industries are now firmly based on complex scientific knowledge. Quite surprisingly, industries that might at first glance be considered as "low tech" are in fact "complex knowledge-based" – such as the food processing industry.

2.3. The second pump: collaboration between users and/or doers – "horizontally" organised innovation

This source of innovation derives from the activities of users and practitioners. They interact in a sector-defined community, designing and building innovative products for their own use and freely revealing their design to others. Others then replicate and improve the innovation that has been revealed, and freely reveal their improvements in turn. Horizontally ordered innovation means that new ideas and methods do not necessarily flow from suppliers. Users and doers are freed from the constraint of the willingness of their commercial suppliers to innovate. These systems involve two major deviations from the private investment model of innovation (which assumes that returns to innovation result from private goods and efficient regimes of intellectual property rights). First, users of technologies rather than manufacturers are the typical innovators. Second, innovators freely reveal the proprietary knowledge that they have developed at their private expense.

Some of these systems are not only complementary with commercial systems of manufacturing and distribution; they may even compete with them. The emergence and upsurge of user communities in sectors like software and sports equipment are a case in point.

The basic concept is that of learning-by-doing – meaning that "doing" or "using" is a powerful (though indirect) way to learn and innovate. But "doing" is not enough to be an innovator and to contribute to create a horizontal system of innovation. Three other conditions are important: that at least some doers/users have sufficient incentives to innovate; that at least some of these innovators have an incentive to reveal voluntarily their innovations; and that they are able to diffuse innovation at low cost.

Learning by doing and by using

At the micro-economic level, learning-by-doing can be related to a particular locus of innovation and knowledge production. This is a process that occurs in the field and not in the R&D laboratory. It is an "on- line" activity as opposed to the "off- line" R&D. On- line learning means that there are both cognitive opportunities and economic constraints.

(Note that "using" here refers to the use of knowledge as distinct from its development: in this context, different kinds of actor can act as a "user" in different contexts. A teacher or production worker, for example, is producing a good or a service for final users, but is still a "user" of knowledge. In some cases, final consumers, are also users of the knowledge used to deliver a service to them – this is true for example of a patient who needs to understand their condition in order to participate in treatment, and a user of a computer programme who can consume it more effectively with greater understanding of its parameters. In principle, students are also important consumers of knowledge about learning, since managing one's own learning is a vital ingredient of the learning process. However, in the context of the discussion below, teachers are regarded as the main "users" of educational knowledge.)

Opportunities are related to the situated character of learning-by-doing (Tyre and von Hippel, 1997). The physical context within which activities are undertaken as well as the interactions between people and physical equipment or between the service provider and the "client" generate problems that create cognitive opportunities for learning. Constraints come from the need to keep the regular activity going: you cannot stop it to run an experiment. In this context, learning is a joint activity and the creation of knowledge a joint product. Knowledge creation is not the primary intentional goal but may nevertheless occur as a by-product of the activity.

There is, therefore, a tension between adhering to expected performance and at the same time learning:

> "In most instances of learning-by-doing, the feedback from experience to inferred understanding is severely constrained. The doers have limited facilities for accurately observing and recording process outcomes or for hypothesizing about the structure of the process they are trying to control. Advances in knowledge that are empirically grounded upon inferences from trial-and-error in a myopic control process cannot be a big help when they are restricted in both the number of trials they can undertake, and the states of the world they can imagine as worth considering" (David, 1999).

This tension (and how it can be solved within "learning organisations") raises the most interesting issues in the economics of learning-by-doing.

The notion of learning as a by-product (as something which is not the main motivation of the economic activity) should not preclude a distinction between first order and second order learning. First order learning is based on repetition and on the associated incremental development of expertise: by repeating a task, I become more effective in executing that task. Such learning is universal in so far as everyone can take advantage of it, from the artisan to the artist, the doctor to the nurse.

Another level of learning is "explicitly cognitive" in the sense that it consists of performing experiments during the production of goods or services. The goal is to test and select a better strategy or a better design for the next period. Through these experiments new options are spawned and variety emerges. This is learning based on an experimental concept, where data is collected so that the best strategy for future activities can be selected. Technical and organisational changes are, then, introduced as a consequence of learning-by-doing. The locus of the learning process is, however, not the R&D lab but the manufacturing plant or usage site. In other words, explicitly cognitive learning-by-doing consists of "on- line experiments".

The importance of experimental learning depends strongly on the nature of the activity: there are high-risk activities in which the agents have to limit their experiments because they could conflict with the "normal performance" that has to be achieved. Airline pilots or surgeons cannot learn in this way. Similarly, people managing a marshalling yard or regulating the flow of subway train traffic will avoid any type of experiment in the normal course of their work. By contrast, a teacher can carry out educational experiments and a craftsman can look for new solutions to a particular problem during the production process. The error element of their (teachers, craftsmen) professional trial-and-error is rarely consequential at least insofar as outcomes can be rapidly assessed and methods adapted. The fact of being able to carry out this type of learning depends on the nature of the risk and the immediacy (or delay) of the effect. Thus, explicitly cognitive learning consists of a series of planned but weakly controlled experiments.

Learning-by-doing is often related to the experience of using a product or a process: using generates problems; problem solving capacities are deployed and learning occurs. Faced with new and unexpected local situations, users have to solve problems that designers failed to anticipate, and are thus in a position to teach and inform those who design systems.

Doers'/users' incentives to innovate

This is the first difference from the conventional model of innovation: users/doers are substituting for commercial suppliers in performing innovative tasks. But do they have incentives to do so? In his depth study for this project, von Hippel identifies three factors that can create such incentives:

- Direct, tailored benefits for the user. Specific improvements in the design of a product can motivate a user to find a solution that will exactly fit with his/her specific needs and circumstances. This contrasts with the supplier's incentive to create solutions that are "good enough" for a wider range of potential users.

- The chance to gain from "situated" learning. Users in a very broad sense acquire a certain kind of knowledge which is particular to a specific site and/or usage. This is the case for the user of a machine tool or a medical instrument. This knowledge is itself an impetus towards innovation.

- The possibility of addressing a problem without the difficulty of communicating "sticky" knowledge about the problem to someone else (von Hippel, 1994). When knowledge is costly to transfer (for instance knowledge about some particular circumstances of the user), the locus of problem-solving activity can shift from supplier to user.

Doers'/users' incentives freely to reveal their innovation

Openness about one's innovation is the second way in which horizontal systems of innovation differ from conventional modes of innovation. Freely revealing new solutions and ideas is a necessary condition for the functioning of communities of users. In these communities multiple potential sources of innovation are identified and each member of the community can benefit from them. If this condition were not met, each user would be obliged to make all the adjustments desired for oneself, which would substantially increase the overall cost of the process. It would consequently have no chance of competing with "average" solutions (more or less suited to everyone) at a lower cost, derived from commercial systems. The sharing and circulation of innovation is therefore essential to ensure a minimum of efficiency.

Freely revealing one's knowledge is not a "rational" action in standard economics. There are however particular circumstances that make it more likely to occur:

- when *reward systems* specifically address the issue of knowledge diffusion and reproduction. This requires a mechanism designed to give credit to inventors without creating exclusivity rights. This is the case of the ingenious reward system in open science, of collegial reputation: here, the need to be identified and recognised as "the one who discovered" something forces people to release new knowledge quickly and completely (Dasgupta and David, 1994). In many historical cases of free circulation of inventions, a financial reward is offered to inventors who agree to diffuse their knowledge, and bonuses are given if the inventor actively takes part in the adoption of his/her technology by others.

- when agents or companies create *"general reciprocity obligations"* in order to capture external knowledge: that is, the right to continue gaining information from others (*e.g.* a scientific network, engineers or users working on similar problems) is conditional on sharing one's own information.

- when a private agent can *benefit from increased "free" diffusion*. A direct result of free revealing is to increase the diffusion of that innovation relative to conditions in which it is licensed or kept secret. Increased diffusion may be beneficial to private agents when *i)* they are interested *in setting a standard advantageous to them,* and thus for other agents (including rivals) to adopt it as well; or *ii)* they are interested in *inducing manufacturer improvements*. This last strategic use of free dissemination is particularly important for users: by freely revealing an innovative product, a user makes it possible for manufacturers to adopt that innovation.

The private benefits of participating in collective action

Now, might such co-operation encourage "free-riding" behaviours (a large number of members of the system stop any creative effort because they can free ride), undermining the whole innovative capability of the system? The answer is striking and counter-intuitive: no, because the private rewards to those who contribute to collective developments are much higher than those available to free riders. Several such "selective incentives" for project participation have been identified in the case of open source projects (von Hippel and von Krogh, 2003):

- Although a freely revealed code (in an open source development project) becomes a public good, its production also creates some *spin-off private benefits,* such as learning and enjoyment, and a "sense" of ownership and control over their work product. In many horizontal system, the technical learning opportunities are enormous and are an important motivation for participation.

- Contributors to a project report valuing the *sense of control* over the direction of their work, which makes a big difference to the nature of work done for a company. Members of such communities choose the project, the task they will work on and their technical approach to that task.

- In many cases, innovations are created by individuals for *private purposes* and are tailored to their individual needs. They are, then, openly revealed and contributed to the community as public goods for whatever general use there may be. To the extent that the conditions faced by the contributor differ from those faced by free riders, the contributor is in a more favourable position than free riders to gain private benefit from the code he/she contributes.

Low diffusion costs

Users/practitioners are not strongly altruistic and they have competing demands on their time during working hours. This means that time spent on diffusing solutions, ideas or innovations within the community or to a particular partner should be not too costly.

The Internet can dramatically reduce diffusion costs, but only for innovations that can be expressed in a digital form – literally a bit string, a long sequence of 0s and 1s. But in many cases low cost diffusion is available rather as a result of opportunities for users to meet in real places for some kind of events (conferences, contests, tournaments, social events). Where electronic diffusion is possible, its cost is constantly low; where diffusion is through people meeting, it is episodically low.

User innovation in different contexts

Not all knowledge-sharing communities have the same combination of elements driving innovation. Some of the most favourable conditions apply in the open development of software. Here, success depends on a) a critical mass of skilled users capable of finding solutions, b) incentives to share knowledge such as rewards to reputation, and c) very low marginal cost for writing and transmitting the information. To the extent that such factors allow the emergence and multiplication of "user-only innovation systems", this represents an important, possibly decisive development in the historical emergence of the knowledge-driven economy.

However, note that the open source example remains unusual in that user-driven innovation not only complements but potentially competes with commercial systems of manufacturing and distribution. In most cases, this is not true because the innovation at stake deals with physical improvements, in which economies of scale matter in manufacturing and distribution. In such cases (*e.g.* sport equipment) users are perfectly able to innovate and to share the innovation, but diffusion is still fulfilled by the commercial system.

In other cases, users have no particular objectives related to challenging commercial supply. An alternative driver can come from community-type structure to improve private and public performance. The clearest cases are in healthcare systems: for example, general practitioners contribute to the production and codification of "evidence-based medicines", in documents that are stored in electronic databases and shared among the community.

Broadly speaking, education systems come under the same category as health care in these respects. Horizontal innovation systems will depend on whether practitioners/teachers have appropriate incentives and opportunities. However, it is also worth asking whether the kind of "innovative exuberance" present in open source projects can be replicated in schools and other educational institutions. These issues are explored later.

2.4. The third pump: modular structures, with freedom to innovate yet joined together as a whole system

At the heart of remarkable knowledge advances in certain industries (for instance ICT) is modularity: building a complex product or process from smaller subsystems that can be designed independently yet function together as a whole. The fact that different companies or different units are working independently on modules is likely to boost the rate of innovation. Modularity can be compared to conducting multiple experiments in parallel. There is, however, a trade off between this freedom to experiment with product design (what actually distinguishes modular suppliers from ordinary subcontractors) and the need for systemic coherence and integration. A particular class of knowledge – integrative knowledge – is, thus, required to achieve integration of modular systems. This class of knowledge covers norms and standards (for quality, for reference and for interfaces), connective rules, certification processes, common platforms, infratechnologies (technologies supporting knowledge infrastructures).

Why is modularity a central way to manage innovation in industrial organisations?

An important element of complexity relates to the evolution of products. New products are rarely stand-alone items; they are more often components of broader systems or structures. In modern technology, modularity is an objective that increasing numbers of firms are pursuing in order to benefit from the specialised division of labour and to create proper conditions for innovation.

A module is a quasi-autonomous subsystem, which contributes to a more complicated system or process by being combined with other similar subsystems through certain connective rules (interface rules). Each subsystem in this “modular” structure can be designed independently, providing the connective rules are followed. Modularisation can be regarded as a generic human contrivance to deal with complexity. In addition, it is a useful method for managing innovation, since it gives designers freedom to try out a wide range of approaches as long as they obey the design rules ensuring that modules fit together (Baldwin and Clark, 1997).

The depth study in this project by Balconi and Centuori. on the microelectronics sector describes well how the appearance of increasingly complex and modular systems allows the production of “integrative knowledge”. This term refers to the features that allow modules of innovation to be connected: norms, interface and quality standards, connective rules, certification procedures, infratechnologies and common product development platforms. Integrative knowledge is used temporarily to guarantee compatibility, interoperability and interconnectivity between sub-modules and modules. It is thus at the base of new forms of division of labour, creating a new regime of product diversity (the consumer can combine different modules to obtain a singular good). It follows that the increasing importance of collaboration in knowledge production cannot be explained only by conventional rationales such as sharing R&D costs. Collaboration may also be important to ensure that modular technologies and loosely coupled systems work properly, by reducing uncertainties and ambiguities.

The trade off between freedom to experiment and general co-ordination

Imagine an organisation composed of three units – two units engaged in production or design of modules and one unit called "the architect or the helmsman" co-ordinating the whole system. Such an organisation must process two kinds of information to achieve its objective. One is visible information; the other is hidden information. The latter kind is concerned with particular needs and objectives which are specific to each of the two modules. Others do not have to know it, so it can be hidden within each unit. On the other hand, visible information is required to clarify the connective rules to be followed for achieving the integration of both modules to create a system. Modularity thus provides a mechanism in which only a fraction of processed information is shared among all agents. The literature on modularity points to several benefits of this in dealing with innovation in complex systems. One is the benefit of having more smaller modules instead of one large one. Another is specialisation, since an engineer working on each module can specialise in localised design and activities. But the main benefit concerns the ability to conduct multiple experiments in parallel, with each corresponding to a different hypothesis or research options.

However, modularisation also incurs costs. Human beings unable to foresee all the uncertainties, find it impossible to enumerate and resolve all possible dependencies among modules. The more complex a system is, the more incomplete the *ex ante* design of connective rules. Thus, modularisation cannot escape from a trade-off between facilitating innovation within modules and optimising the whole system.

Coping with this trade-off in three different modular forms

One can evaluate three generic forms of modularity in terms of their ability to cope with this trade-off (Aoki and Takizawa, 2002):

- "*Hierarchical decomposition*" describes a system whose key features are pre-designed by a single "architect". This architect is specialised in processing exclusively the visible information and determines the connective rules prior to the design of the modules. Even if something occurs in the environment after activities in the respective modules begin, only the architect can decide changes in the connective rules. Each module is only engaged in processing idiosyncratic information required for its activity, given the visible information transferred by the architect.

- *Information assimilation* is a system in which the architect leads but does not create inflexible system features. Connective rules continue to be fine-tuned even after the activities in the respective modules begin. Information about changing conditions is exchanged between the architect and the modules as well as between the modules. In other words, the visible information is propagated back and forth between the architect and the modules.

- *Evolutionary connection* involves multiple architects and multiple agents engaged in the design of each module, with continuous assimilation of new information. Activities are carried out in parallel and duplicated. Each agent is not only engaged in processing hidden information, but also processes the visible information independently in a limited way. Through information exchanges between the modules and the architects, a few connective rules may emerge in an evolutionary way. The architects will select and combine already designed modules that are most compatible with the connective rule that they select to form a product system. The market finally evaluates which system will have the highest value.

Clearly, the more complex a system is the more efficient forms (second and third points above) will be, since they can adapt connective rules to complex and evolving conditions rather than fully pre-defining them.

Modularity in education

Modularity is the usual way of organising activities in education. Indeed, teachers or classes are sub-modules; schools are modules while central authorities (those, for instance, which are regulating the curriculum) are playing the role of architect. But to what extent are those within classes and schools able to innovate, as part of a system-wide learning process? As in other sectors, this issue requires us to study not what goes on within each "module" (this is the "hidden information" for the system as a whole, and needs to be studied by looking at the three other "pumps"), but to focus on innovation "at the interfaces": how connections are made and innovation generalised within systems; in education, an essential connection is the coherent certification of educational outcomes in a system that allows multiple processes and hence experimentation. The trade-off between freedom to experiment and general co-ordination needs to be properly managed. These issues are explored further below.

2.5. The fourth pump: information and communication technologies

ICT as a knowledge instrument

The ICT revolution is of crucial importance in so far as it involves technologies geared to the production and dissemination of knowledge and information. The immense potential for economic change offered by the new ICT system is particularly relevant to situations in which the main object of the transaction can be digitalised – which is the case for much, albeit not all, knowledge.

Information technologies can affect knowledge creation in a number of different ways. For a start, the mere fact that one has the capacity to create such a wealth of information is truly revolutionary. The long evolution of communication of the "instruments of knowledge" from the invention of language and writing to modern ICT is still far from complete: an enormous amount of progress remains to be made in such areas as information search systems. Yet today, these instruments offer unprecedented possibilities.

Second, ICT reduces the need for physical proximity in many cognitive activities (*e.g.* distance learning, distance experimentation). Access from a distance not only to writing but also to other modes of expression of knowledge (especially gestures and words) revolutionise possibilities for learning. It is true that many activities cannot be coordinated by virtual means alone. The emulation and spontaneity generated by physical presence and social groupings often remain crucial. Likewise, direct face-to-face exchanges are important when they enable other forms of sensory perception to be stimulated apart from those used within the framework of electronic interactions. However, the influence of distance is waning now that the technological capacity is available for knowledge-sharing, remote access and teamwork, and organising and coordinating tasks over wide areas.

Third, ICT is at the base of new modes of knowledge production. It enhances creative interaction not only among scholars and scientists but among product designers, suppliers and the end customers, for example. The creation of virtual objects that can be modified *ad infinitum,* and are instantly accessible to one and all, serves to facilitate collective work and learning and dramatically to increase the speed of prototyping and designing new products. In that respect, the new possibilities opened up by numerical simulation represent a key factor. ICT allows the exploration and analysis of the contents of gigantic databases, which is in itself a potent means of knowledge enhancement (in natural, human and social sciences and in management alike). Research stimulated by such possibilities has a strong influence in some areas of managerial work.

Fourth, the above three ways in which information technologies affect knowledge creation can be combined in the development of large-scale decentralised systems for data gathering and calculation and the sharing of findings. Such systems characterise research currently underway in the fields of astronomy and oceanography, for example.

Finally, ICT provides powerful opportunities for collective actions – *i.e.* the sharing of "rich" messages among a very large number of people – allowing for the creation and expansion of virtual communities.

ICTs as enabling the transformation of "systems of service provision"

New ICTs increase the power of individual and collective production and circulation of knowledge while creating new tensions and difficulties. To overcome those conflicts and resolve these tensions, new adaptations and innovations in other technological and social domains are necessary. Thus, a complex set of interdependent changes support the transition of communities and/or sectors towards new forms of knowledge-driven activities. A depth study by Mansell and Curry (see Box 2.1) shows very well how the performance of the emergency health-care system may improve through the intensive adoption of ICTs. But this case study also shows the host of other transformations (concerning organisations, knowledge management, training and cognitive and mental representations of codified knowledge as opposed to contextual and tacit knowledge) which are necessary in making it possible to realise fully the transformation potential offered by ICT.

The health example here again has some lessons for education. It is one thing to assimilate ICTs as a tool within the school, but another to use it to alter instruction fundamentally. As with health, this may require more radical change than has yet been seen, creating a form of what Schumpeter called "creative destruction". Implementing an ICT system is by far not the end of the story. It is at the best a way to catalyse system transformation: computerisation involves much more than computers. Rather, as said by Brynjolfsson and Hitt (2003), computer and ICTs are just the tip of much larger iceberg of organisational investments and knowledge management practices.

Box 2.1. **Emergency health-care as an emergent knowledge-driven system: some key points from Mansell and Curry's depth study***

In the UK's National Health Service, a new system for communication with users illustrates the potential and limits of an ICT-based initiative as an agent for change: an enabling technology is not sufficient on its own to transform knowledge across a sector.

"NHS Direct" is a 24-hour health information and advice help line with a remit to provide faster and easier access to advice and information about illness and the services provided by the NHS. Based on a software system (Computerized Assessment Software System) transferred and adapted from the Insurance sector, the service provides multiple services including NHS Direct Online, Information Points, NHS Direct in Vision (digital TV) and a Self-Help Guide. The increase in the number of users since the start is spectacular and published evaluation of the telephone help line services indicates that these services are well-used.

However ICT as an enabling technology is not enough on its own to transform a sector. Many obstacles have not been magically removed:

- Co-ordination and communication between the various communities of professionals involved in the system have not been greatly improved; boundaries are still impermeable while the full realisation of the potential of the new system should require effective and efficient coordination mechanisms between General Practitioners, Accident & Emergencies Departments, Minor Injuries Professionals and Ambulance personnel. The solution to this problem – circulation of individuals who can share and report their experiences with the new development of NHS Direct – is proving difficult to implement.
- Another source of difficulty concerns the recruitment of high-skilled employees to work in the NHS Direct System (these people must be prepared to make important health care decisions). One way to solve this issue without contributing to staff shortages in hospitals is to support and encourage post rotations between various parts of the whole health care system. The application of this principle is, however, limited by the cost of training a large fraction of health care employees in using the new technological system.
- A major source of resistance to the introduction of ICT decision support as NHS Direct comes from the doctors. Two arguments are usually given: no time for training in the use of ICT systems; and, more fundamentally, a general scepticism about the capacity of an ICT system to deliver enough knowledge to take a health care decision: "no corpus of explicit knowledge embedded within an ICT system could be sufficiently context-specific to meet the needs in an emergency… and no amount of ICT use could substitute for the trust relationship the doctor has with the paramedics".

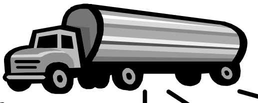
The study concludes that there is a need for investment in people, new institutions, and technology over a 20-year period of transition to a more knowledge-driven public sector health care delivery system.

Full study paper: "Emergency Healthcare: An Emergent Knowledge-driven System", by Professor Robin Mansell and Dr. Richard Curry, *www.oecd.org/edu/km/mappinginnovation*

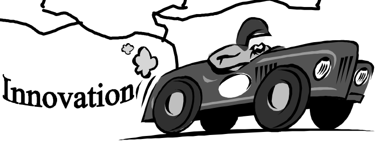
2.6. Four pumps to fill up with innovative capacity

The four sources of innovation or modes of knowledge production reviewed above can be summarised in the following figure.

Figure 2.1.



	PUMP 1	PUMP 2	PUMP 3	PUMP 4
Innovative opportunities	Scientific advances	User needs and capabilities	Modular systems	ICT as an innovative tool
Critical actors and relationships	University-start up enterprises; Large companies with R&D capacity	Horizontal communities	Architect and module designers Rules for their interaction (several generic forms)	ICT (incl. software) suppliers, managers employees, stakeholders, customers
Contributions to the knowledge base of the sector	Scientific knowledge of direct relevance for improving processes and products	Practical knowledge which may be widely adopted within a community	Integrative knowledge (norms, standards, certification, common infrastructure) Visible information	Codified knowledge of various kind able to be processed through ICT systems Tacit knowledge empowering people to use and interpret codified knowledge



Yet these ideal types (pumps) are rarely identifiable in a pure form. They are born at certain points in history, in specific limited domains. Their importance grows as they combine and hybrids are formed. Many "real" innovation processes are the result of combinations between the different models described above. Boxes 2.2 and 2.3 give two examples of how this occurs within particular sectors.

Box 2.2. **Combining sources of innovation I: the unique case of microelectronics: some key points from Balconi and Centuori's depth study***

The microelectronics industry is exceptional in combining all four of the "pumps" described above to generate a rapid pace of innovation and knowledge advances. In a sense it can be viewed as a "paradigm" of innovation processes in the knowledge economy. It is based on a rare combination of competition and collaboration, private and (quasi) public knowledge, science contributing greatly, modularity and integration, a role for doers/users, and the importance of ICT as an innovative tool:

- There is a science-based innovation aspect, clearly illustrated by the importance of the role of university in the production of knowledge in the field of circuit design. While scientific knowledge is clearly necessary about the physics of materials underlying VLSI, Microsystems, sensors, biochips, it is also critical at the stage of circuits design: the methods required to create new sophisticated design are typically scientific in character, as they involve basic understanding and theory building. Actually the "creative engineers" who perform this kind of research have to come up with innovative methodologies, new theories and mathematical formalisations of problems concerning electrical circuits. They also have to develop a full analytical understanding of the fundamental limits of circuits, in order to avoid wasting time in attempting to overcome them. In such circumstances relations between university and industry are very important. A particular channel of knowledge transfer is constituted by PhD students, who are sent by their professors to make presentations of their research or thesis in different companies. On the other hand, given the application-oriented character of their research endeavour, university researchers look at industry for "direction" in general, and more specifically for problems to be solved.

- There is a "horizontal innovation system" aspect: beyond belonging to a start-up enterprise, the most productive designers have a sense of belonging to a professional community, which frequently has a localised base (*e.g.* Silicon Valley) and is sustained by the high mobility of these people. Although rivalry conditions are particularly high, some systems of knowledge sharing and innovation diffusion operate within such communities. Beyond personal reading of recent literature, a common way in this industry to be in the vanguard is to attend panels and conferences. IEEE has local sections and organises panels or short classes. On these occasions designers meet, make new friendships and talk to each other. It happens that they share their technical problems as well as their opinions about potential solutions. A common habit is to organise informal gatherings with colleagues and friends who belong to the same working area. Such forms of knowledge sharing are common to many sectors, but are particularly intense (as in this sector) when proprietary know-how has the following attributes: it relates to a very high number of production steps; no single step is, therefore, vital to the firm. Moreover firms know that all process steps can be independently developed by any competent player, given an appropriate expenditure of time and money.

- There is an integration-oriented innovation model: since no company can develop internally all of the resources and skills required, a market for design modules and virtual components has emerged. Such a modularisation of systems means that the main complexity in microelectronic design is no longer the creation of a single module, but mainly system integration on the same pattern of different modules. Usually, firms making system-on-chips (SoC as a new mode of highly integrated devices) create a team with the task of integrating the modules. The leader of the SoC project has a very important role both technically and relationally.

- Finally, the role of IT as an innovative tool is self-evident. Advances in IT create the momentum for knowledge advances in microelectronics.

* Full study paper: "On Creation and Distribution of Knowledge in Microelectronics", by Margherita Balconi and Alfonso Centuori, *www.oecd.org/edu/km/mappinginnovation*

Box 2.3. **Combining sources of innovation II: patients' organisations and their involvement in research: some key points from Blume's depth study***

This case provides an example of the emergence of knowledge-driven communities based on the combination of three innovation pumps. Innovative activities are based on: science and on users' (or laypersons') knowledge, and enabled by ICT. The crucial factor is the participation of "lay-experts" in the production (and use) of scientific knowledge. Health is a perfect example of an area in which laypersons unquestionably possess knowledge of use to scientific investigation, and thus is particularly well-suited to this type of innovation. Environmental improvement activities can also afford opportunities for close collaboration between lay-experts and scientists. In the case of health:

- the science based aspect is of course extremely strong because one of the objectives of these patient organisations is to influence the research agenda; which requires strong connections with scientific research;

- the horizontal system aspect is also important. Most of these communities work and operate on the same basic principles as the user communities described by von Hippel. Members of the community are willing to produce information about their illness, the kind of therapeutic methods which succeed or fail; they are willing to share and reveal it for free; diffusion costs little.

- the ICT aspect is also strong. ICT provides not only a good knowledge repository (which is an important role in a sector where storing and retrieving factual knowledge is extremely important), but also the infrastructure for discussion groups that allow patients to exchange experiences in an effective way.

* Full study paper: "Patients, Patient Organisations, and the Production of Medical Science and Technology, by Stuart Blume, *www.oecd.org/edu/km/mappinginnovation*

2.7. The four pumps and the education sector

The "four pumps" framework is now used to discuss the potential impact of these various sources of knowledge (science, horizontal systems, modular structures, ICTs) on the transformation of the education sector. The policy implications of this framework are discussed later.

The first pump: science and innovation

How important is scientific evidence in driving innovation in education? Strictly defined scientific experimentation has tended to play a limited role in the day-to-day improvement of education systems. However, some specialists believe that education is now on the brink of a scientific revolution that has the potential to transform profoundly policy, practice and research. They emphasise the possibility of much greater use of randomised controlled trials or randomised field trials to generate scientific knowledge and robust evidence on a broad range of topics in a sector like education (Fitz-Gibbon, 2001, Slavin, 2002 and see Box 2.4). Others take a different view of where knowledge is grounded, or epistemic approach, focusing rather on best practice as expounded by expert practitioners rather than formalised, scientifically proven methods. These two views can be characterised as "scientific" and "humanistic" and are discussed by Foray and Hargreaves (2003).

Box 2.4. **Towards a more scientific approach to educational improvement?**

Two general trends have increased the demand for more research and information about education in several OECD countries. First, governments increasingly are steering educational systems by goals and standards rather than governing by rules and regulations. This raises the need for more explicit R&D information on the outcomes of education practices and policies both at regional, national and international levels. The wide use of the OECD's Programme on International Student Assessment (PISA) should be seen in this light. Second, several governments are promoting "evidence-based" policy making. The core of such an approach is that policy initiatives should, as far as possible, be underpinned by evidence and research.

A good example of such an approach can be found in the US Bush Administration's first domestic initiative, the reauthorisation of the Elementary and Secondary Education Act, entitled No Child Left Behind. The Act mentions "scientific based research" 110 times. Stimulated by the legislation's attempt to define what constitutes rigorous scientific methods in researching education, the National Academies Press has published a useful analysis of the ways in which scientific methods can be applied in this field (*Scientific Research in Education*, 2002, *www.nap.edu/books/0309082919/html/*). It points out that despite a historical scepticism about treating education as a science, today a number of new methods are being brought into such research, including new observational techniques, new experimental designs, new methods of data gathering and analysis and new software packages for managing and analysing both quantitative and qualitative data.

The scientific approach stresses the need for experiments to yield formal and explicit knowledge of "what works", the activity involved being carefully specified and disseminated through written and visual media (articles, books, videos, etc). The humanistic approach identifies best practice as embodied in outstanding practitioners who disseminate their tacit knowledge and practice through modelling, mentoring and coaching.

A parallel is medical research. During the 19th century the medical profession changed its epistemic culture under the influence of modern science, and this led to the rapid growth and accumulation of medical knowledge that continues to this day. In modern medicine the sub-communities of the various medical specialties fall within the epistemic culture of science; those that do not are given the generic name of "alternative medicine", which demarcates (and perhaps stigmatises) a starkly different epistemic culture.

Randomised controlled trials as the "gold standard"?

One of the most significant developments in modern medicine has been the randomised controlled trial (RCT), the significance and use of which grew rapidly after its application to tuberculosis in the 1940s. Today the RCT is widely treated as the evidential "gold standard" for demonstrating "what works" and what is medical "best practice". In branches of medicine that adhere in whole or part to an epistemic culture of humanism, objections are often raised against the RCT, including ethical reasons. There is, however, a growing consensus that in this sector RCT is most likely to foster the generation of reliable knowledge when the following conditions converge (Shavelson and Tourne, 2002): "treatment" is well defined; careful control is possible; randomisation is often possible; and there is a shared knowledge base related to scientific areas (physiology, pharmacology).

As far as education is concerned, there is a deep rift between two fundamentally opposed epistemic cultures. On one side stand those who believe it possible to treat medicine as a potential model for the advancement of knowledge in educational practices and who are thus currently inclined to support the application of the RCT to education problems. On the other side stand those who reject this totally and favour the humanistic approach that has deeply influenced work in the arts and humanities in universities. For this latter group, "best practice" consists of the judgement, based on depth and breadth of experience, of the individual practitioner as a unique case, and is achieved through "reflective practice".

As regards the methods to create best practices, the educational community still appears as a divided community. Many academic educationists are deeply hostile to the scientific approach and want to stand alongside groups such as consulting firms with a different notion of "best practice" and how it is defined, accumulated and disseminated. Hammersley (2002), for instance, adheres mainly to a humanistic mode, and whilst he does not deny the possibility of experimental mode of educational research, he insists that the scope is very limited and concludes that current policy is raising expectations of practical applications that can only result in severe disappointment. However, it is increasingly recognised that research using experimental or quasi-experimental designs, preferably with random assignment is important to undertake when issues of causality and systematic effects of an innovation are raised. While other forms of investigations than experiments (such as descriptive research) are essential for many research objectives, RCT is the relevant design for studies that seek to make causal conclusions, and particularly for evaluations of educational innovations (see Box 2.5).

Box 2.5. Methodologies to evaluate educational innovations

Historians of technology and industry show very well that the way industries are dealing with this step – evaluation and analytical understanding of innovation – is crucially influential on the rate and speed of knowledge creation and effective innovation. A fundamental step in any industry's evolution is when research methods and research capacities (including cognitive and economic capacities) combine properly to allow for large scale experiments, which are systematically carried out to evaluate and control any new methods, tools and practices. In the sectors which are not yet "knowledge-driven", innovations may occur but no or very little evidence is available because one crucial link is missing in the system and policy makers have to act with little information. In sectors which are fully "knowledge-driven", most innovations are transforming into evidence through systematic and rigorous evaluations.

An important paradigmatic shift for educational research is associated with the promotion and development of this particular type of research through which rigorous methodologies make it possible to transform innovations into evidence.

The chart below shows that sources of innovation are multiple and very diverse: role of teachers as innovators; contributions of basic research to improve our understanding of fundamental cognitive laws and contributions of descriptive and analytical research in theory building and suggesting variables to be deeply explored; role of ICTs as a general-purpose technology generating many opportunities to innovate. Moreover the system of innovation in the education sector involves practitioners (teachers), educational researchers, ICTs and instructional technologies providers as well as school administrators assuming the knowledge management tasks (coordinating horizontal and vertical networks).

Any of these domains is potentially powerful in generating new tools and new organisational designs to improve teaching practices.

The contribution of science to the advance of knowledge deals, however, with the next step in the innovation process: the evaluation and analytical understanding of innovation, whichever is the source considered. Research questions at this stage fall into three categories:

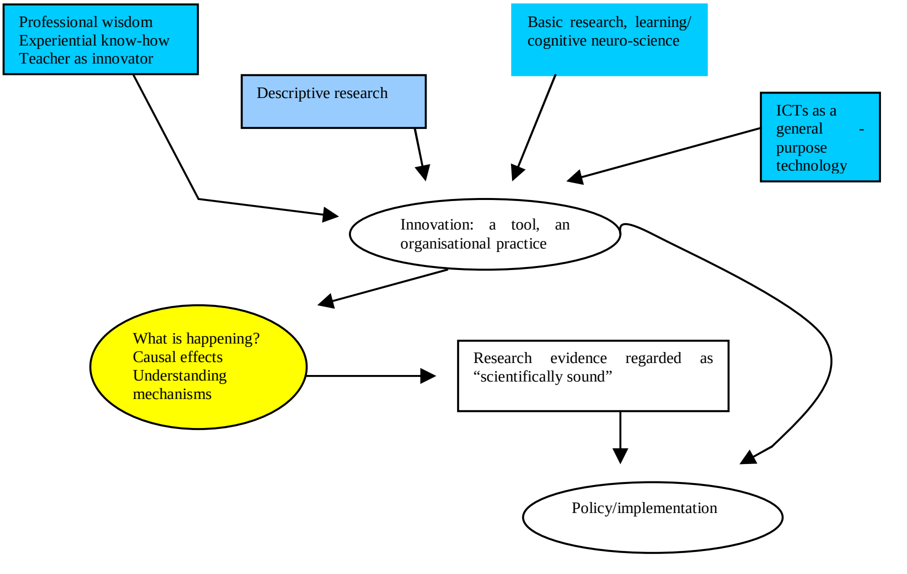
- What is happening?
- Is there a systematic effect?
- Why or how is it happening?

The first question invites *description* of various kinds, so as to develop a theory or a conjecture, or identify changes over time among different educational indicators.

The second question focuses on establishing *causal effect*. What is the effect of the innovation considered? In case of an improvement which is observable after the innovation has been adopted, is it really an effect which can be ascribed to the innovation? Is an innovation which has proven to be successful in a certain context generally applicable? All these questions deal with the problem of transforming an innovation into an evidence for policy making.

The third question confronts the need to understand the *process* by which the considered innovation causes an effect.

It is thus clear that particular methods are better suited to address some research questions rather than others. For instance, the search for causal inference does require research using experimental or quasi-experimental designs, preferably with random assignment (to reduce any risk of selection bias).



From sources of innovation to policy: the need to produce evidence

In medicine, general practitioners or family doctors share a broad commitment to the scientific approach with the intellectual leaders in higher education, medical schools and teaching hospitals. In primary and secondary education, by contrast, teachers in schools remain largely ignorant of, and entirely indifferent to, the battles between competing epistemic cultures among the schools of education which conduct research and control the initial training of teachers. Sometimes their inclination is to favour the humanistic mode of research, for here they are less intimidated by their lack of research expertise. Generally, however, they are free from pressure to take sides on issues of epistemic culture and can, like practising doctors, find ways of combining the scientific and epistemic cultures in their day-to-day practice.

At present it seems unlikely that one of the two epistemic cultures will prevail in university-based study of education or among the rapidly growing, if still relatively small, body of teacher-researchers. The teaching profession's community of practice will thus not subscribe to one dominant approach, as in the case of medicine, but will come to share elements of *both* epistemic cultures in a new synthesis of practice that selects and blends elements of both.

This is why the "four innovation models" framework is useful in suggesting that the science-based model is extremely important but will never cover more than one part of the whole "innovation tank" of the education sector.

Experimentation and the new economics of R&D

The low levels of R&D expenditure, R&D employment, science-based innovation and performance in the education sector may well be explained by the lack of clear results and improvements derived from experimental methods. It is possible that some policy push may reverse this spiral of stagnation: rigorous research demonstrating positive effects of replicable programmes on important students outcomes would lead to increased funding for such research, which would lead to more and better research and therefore more funding. This is a system with two equilibria. It may be trapped in a low-level equilibrium. This is what happens in many countries when low level of R&D funding is likely to generate weak results and performance which creates a rationale for decreasing further R&D investments. Under a different set of circumstances, however, the system may be situated in a virtuous circle of high investments in R&D, relevant and useful results, performance improvements which creates a rationale for increasing R&D further.

However, entering this virtuous circle requires an understanding that a shift is needed not only in research methods (as a cognitive problem) but also in the economics of R&D. This requires some difficult issues to be considered: the appropriate level and mechanisms of funding, the appropriate supply of skilled researchers, instruments and tools and methods of exploitation and “protection” of the knowledge produced – which may have not only a high social value (benefit to students), but also a high private value (for suppliers of new pedagogical material and software). Thus an acceptance of the scientific value of R&D in education may not be sufficient to stimulate appropriate research: these other “economic” factors are also necessary ingredients.

The second pump: horizontal system of innovation

The first condition for a horizontal system of innovation to be in operation is certainly met within the education sector. Primary education is a sector where forms of “learning-by-doing” are an important mechanism for generating knowledge. As Huberman (1992) observed, teachers are primarily artisans, working alone in a personally designed environment where they develop most of their skills by trial-and-error “tinkering”. An interesting parallel with doctors can be considered. Primary education and health care are sectors where forms of “tinkering” are an important mechanism for generating knowledge. 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 practice method 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. However, the learning potential of these processes is less well exploited at the system level in education than in medicine.

Finding the private benefits of the collective model

While educators therefore have plenty of incentive to innovate privately, the second category of incentive identified above, to share knowledge and diffuse it among other potential users, is not well fulfilled in this sector. In policy discussion, the notion of a network is used frequently precisely to address this problem of insufficient “spillovers”. It is true that there are numerous experiences of knowledge sharing and diffusion based on networks. CERI has documented many cases of identification, formalisation and diffusion of best practices through networks and other kinds of co-operative structures (see OECD, 2003). Yet the very fact that these examples are being so vigorously promoted reflects the situation that such networking has yet to become the norm. Observers generally agree that they do not find the same kind of "innovative exuberance" that has been featured in many examples of horizontal systems described by von Hippel.

The crucial thing that von Hippel shows is that neither the private investment innovation model nor the pure collective action model can fully explain the strong performance of open source development projects. And the type of incentive that do exist for teachers to contribute are probably much closer to what von Hippel calls a private-collective innovation model than a pure collective action model.

This means that a big task remains to find, identify and promote the private benefits that are available to contributors to a collective project and not to free-riders. This requires greater understanding of which "selective incentives" will put teachers in a position *to benefit privately from providing a public good.*

Networking is certainly a useful metaphor showing that the diffusion of knowledge requires some forms of organisational practices involving connectivities and communication. However, a metaphor is not the same thing as a well worked-out economic model involving the provision of incentives and the design of coordination mechanisms appropriate to the economic processes of knowledge creation and diffusion. A range of selective incentives need to be identified for prompting teachers to reveal and share their practical knowledge.

The third pump: modularisation as a mechanism to promote innovation

Modular structures are the rule in the organisation of educational programmes. Teachers or classes effectively operate as "sub-modules", schools as "modules" and any kind of central, regulatory agency as the "architect". As in other sectors, it is useful to think of these modular structures in terms of mechanisms in which only a fraction of processed information is shared among all agents, with the other information hidden within each module. Issues for education are similar to the issues raised by modularity in industrial organisation. They concern the trade-off between using modularity as an opportunity to boost innovation (modularity as a multiple experiments structure) and maintaining coherence and cohesion in the whole system. The more complex a system is, the more unpredictable the multiple innovative paths will be, and the more incomplete would be any system in which rules are pre-set by a system architect. The issue to be addressed is whether a particular generic form of modularity – "hierarchical decomposition" (with the architect presetting the rules), "information assimilation" (with the architect in the lead but adaptable) and "evolutionary connection" (without a single architect) – may be the most suitable to create a good balance between innovation and co-ordination in the education sector.

Today, systems of education mainly work on some kind of "hierarchical decomposition": even if something occurs in the environment after activities in the respective modules begin, only the architect can decide changes in the connective rules and visible information, such as educational outcomes as measured by standardised assessment of students. This is highly stylised description of the "static nature of current curriculum provision" (Kennedy, 2001), with change tending to take place only at the margin: despite important shifts in school populations, the nature of work, and social conditions affecting young people, the curriculum remains largely intact. Shifting to the second form of modularity – "information assimilation" – is a way to create more space for decentralised innovations, and to exploit fully initiative taken within schools and classes, while trying to ensure the continuous adaptation of the connective rules (the visible information) even after the activities in the respective modules begin so that the whole system maintains its cohesion and coherence. This second form is thus a highly stylised fact of organisational conditions supporting deregulated curriculum: new connective rules or standardisation of interfaces among modules might come to emerge in an evolutionary way.

The third modular form is going one step further, implying that system innovation is to a large extent the sum of the innovation within each educational institution, with an evolution of the rules that bind the system together rather than centrally driven decisions about what may need to change. For example, this may imply that schools and teachers would be involved in developing their own forms of assessment of learning as understanding about cognitive skills evolves, rather than having preset curricular and assessment standards. This example shows just how difficult it may be to develop a truly evolutionary style of innovation within an education system, not least because final users (*e.g.* employers) demand a level of simplicity rather than complexity in the form in which educational achievements are certificated.

Underlying the problem of how to make better use of modular structures in education is a paradox: the organisation of education is intrinsically modular, yet the need to produce recognised and therefore to some extent commonly designed outputs creates an inherent pressure for a degree of central control, co-ordination or standardisation. The modular mode of production comes from the fact that education is produced directly from original producer to final user: there are no "intermediate products" between the teaching and the learning process. Thus if a teacher uses a new method, this does not directly affect the teacher in the next classroom. Yet precisely because of this, there is a need to make the products of education recognisable, for example through assessment of learning. While in principle specifying the outcome is not the same as specifying the process, in practice the way that assessments take place can strongly influence the manner of teaching. Moreover, even though teaching is modular in its nature, the importance for the student of one module of learning preparing for the next one does limit the autonomy of the individual teacher.

In practice, nobody is more intensely aware of the need for co-ordination than government ministries and public agencies charged with answering for the overall output of the system. For this reason, even when advocating greater local innovation and decentralisation, governments often find it hard to create conditions that optimise the modular potential of the education sector. OECD/CERI analysis of innovation in this sector (under the theme "Schooling for Tomorrow") has found that decentralisation and innovation are not always synonymous: "the 'rolling back of the state' is often combined with a 'rolling in of new, dispersed forms of control'". Moreover, schools and teachers have found it hard to learn effectively when they are in the spotlight and the necessary failure that comes with experimentation is poorly tolerated at the political or administrative levels (Hirsch, 2003, pp. 173-174).

All these constraints do not mean that it is impossible for individual teachers to innovate. However, they help explain why such innovation has not so far lived up to its potential, and why in future it can only do so if the architecture of the system as a whole remains co-ordinated to some degree.

The fourth pump: ICTs and innovation

Although ICT as a knowledge transfer instrument is empowering most of knowledge and information providers and users in our (knowledge) society, schools are integrating ICTs-based instructional practices into conventional classrooms at a glacial pace (Guthrie, 2003). While, in many sectors this fourth model of innovation is becoming the great driver towards more effective and efficient organisations, processes, products and services, this is not yet the case for education. Why do schools not rely upon technology for their core activities as intensively as much of modern society (see OECD, 2001 for a general overview of these issues)?

The two main explanations are either no longer relevant (at least for some countries) or only partially relevant. The first explanation concerns the "supply side" and, as such, has strongly influenced policy thinking. However, even countries where insufficient supply of computers is no longer an issue have yet to meet adequately the challenge of re-inventing schools through the new instructional technologies.

The other more subtle explanation is the so-called "easy assimilation" hypothesis: new ICTs have not fundamentally altered the structural components of teachers' core of instructional endeavours because the main structures of teacher's activity are considered as "unchangeable". Thus, ICT remains at the periphery of classrooms, isolated in special laboratories and is thereby "easily assimilated" because its adoption does not provoke any "creative destruction". According to Schumpeter, who made important conceptual contributions to the theory of innovation, the essence of innovation lies in the destruction of an old combination and realising a new one.

This is the conclusion of both the Becker studies and Cuban book about the US education system: instruction in America is not significantly influenced by electronic technology, despite the fact that the supply side problem has now been largely solved. The depth study by Mansell and Curry on emergency health care shows how far and deep is the creative destruction process to make ICTs capable of fundamentally altering the structural components of core activities in a given sector.

Thus, if supply failure is no longer the main explanation of the problem (although it can still be, of course, a major problem in many countries), policy thinking has to address the question of the essential ingredients of demand which are missing.

2.8. Conclusion – Policy challenges

Figure 2.2 summarises where the education sector stands with regard to the four models of innovation and derives policy issues. This initial overview has illustrated ways in which the "four pumps" of innovation can be viewed in education. It shows how there may have been a tendency for this sector to use some pumps more actively than others (Michel, 2001). In particular, ICT and horizontal networks seem to have been more widely used than scientific R&D and modularity as a method to enable innovation – although a more systematic comparison of national systems of educational innovation would be needed to verify this. This section has not tried to imply that every pump will be equally relevant for each aspect of educational innovation, but rather that each pump's *potential* needs to be explored in order to optimise the strength of innovation in a sector in which steady improvement in performance has become a priority.

Box 2.6 presents a particular vision of the future in which the pumps are used more actively in education, based in particular on recent development in England.

Box 2.6. **Innovation in the education sector: accelerating change? – Some key points from a working paper by Professor David Hargreaves***

Educations systems have so far been slow to respond to the challenges of the knowledge-driven economy. This could now change, although at what speed is uncertain.

Judging from the English experience, on which this paper is based, there are signs that education systems are now showing an inclination to innovate, driven partly by a desire to improve their performance as measured in international studies such as PISA. Yet conventional "improvement" strategies have limited potential, especially if the aim is to transform the ways in which students think: to create not just "higher", but "different" outcomes. The language of "transformation" is now evident in mainstream policy discourse, at least in England. Radical innovation involving, for example, fundamental change in approaches to teaching and learning cannot be achieved through incremental change alone.

Most schools are worryingly similar in their structures and methods to those created in the industrial revolution. New technologies do not on their own bring transformation. A more promising resource for innovators may come from the new modes of operation in the most impressive of today's workplaces. One approach is to re-design schools to serve as a preparation for life in the companies of tomorrow's knowledge economy.

Transformation of professional and institutional norms in education will not arise spontaneously: it must be engineered by imaginative and courageous policy makers. Yet a top-down approach will not work. Instead, the education community in general and schools in particular need to learn certain norms that allow them to be innovators. This requires them to build, identify and mobilise intellectual capital – knowledge and understanding of what works, drawn from throughout the educational community. The key is to *leverage* such knowledge to ensure that it is applied to change. The introduction of ICT in schools offers a powerful illustration of how the availability of new methods and tools have only an incidental effect on teaching and learning unless they are also accompanied by organisational capital: a deeper understanding of the transformational power of these tools.

By working as communities to build organisational capital, schools need to move beyond individual "tinkering" by teachers (using trial and error in their methods) and yet not rely on top-down directives. In order to foster knowledge-intensive communities in which large proportions of members are involved in the production and reproduction of knowledge, an essential task is to ensure that teachers have:

- the *motivation* to create new professional knowledge;
- the *opportunity* to engage actively in innovation;
- the *skills* of testing the validity of the innovation; and
- the *mechanisms* for transferring the validated innovations rapidly within their school and into other schools.

User networks and organisational capital

Is it possible to create in education the kind of "horizontal networks" described by von Hippel (Box 1.1 above)? This requires teachers to become more accustomed to developing and transferring their ideas and knowledge. It also requires an important element that has been missing from education systems – an ability to take risks and to "fail intelligently". This element of experimental innovation is lacking not just because individuals lack the understanding of how to use trial and error, but because of the system's present response to failure. Political demands for success create strong pressures not to fail, and increasingly create stigma for doing so.

Leadership, too, needs to change from the current school improvement model if it is to support the development of organisational capital. It needs to move away from a focus on "managing change" – which most commonly refers to change that is externally imposed. Rather, the principal needs to mobilise a school's intellectual and social capital, especially in relation to teaching and learning, in ways that achieve high leverage, by a combination of incremental and radical innovation. Schools must still be managed, but with an emphasis on managing knowledge inputs and outputs, rather than on managing people and tasks.

As in other industries, true "horizontal" based innovation needs to create networks that reach beyond the boundaries of the individual organisation. Increasingly it is involving collaboration across schools. An innovative school has four options: keep its innovations to itself, to protect its competitive advantage; sell its innovation; share its innovations within a defined network community of learning; or freely reveal, as illustrated in von Hippel's open source projects. The second (selling) has occurred in limited circumstances, but the third (sharing within a self-selected network) is probably the most likely development in the near future, because it allows both the exchange of very different innovations to the mutual benefit of network. One feature of current UK experience that is transforming horizontal innovation is the development of "specialist" schools, allowing greater scope for informal trading of comparative advantage across institutions.

Beyond linear R&D

The old model of university-based educational research has failed to have transformational outcomes for schools, and indeed the overall impact of such research has been disappointingly small. As Cockburn has shown for the pharmaceutical industry (see Box 3.4 below), the emergence of intermediate organisations in between academe and practice can start to change and blur the relationship between those who produce knowledge and those who apply it. In the case of education, at least in England, two particular trends can be observed. First, a growing number of intermediate organisations and agencies (many of them agents of central government) are getting involved in both R&D and its application in practice. Second, in partnerships with such organisations, practitioners are able to be more influential as clients than they ever were with university researchers.

In this departure from a "linear" form of R&D, school practitioners have yet to find and exercise a collective "voice" to institute radical changes in priorities. However, the product of a more interactive style of knowledge production can be seen, for example, in the development of techniques for "assessment for learning" – previously known as formative assessment. This reflects a more general challenge to education systems to foster genuine learning – and true motivation to learn – rather than simply strong performance in tests.

* "Policy for Educational Innovation in the Knowledge-driven Economy", working paper for this project, *www.oecd.org/edu/km/mappinginnovation*

Figure 2.2. **The four pumps in the education sector: opportunities, problems, challenges**

	Pump 1	Pump 2	Pump 3	Pump 4
Innovative opportunities	Scientific advances	User needs and capabilities	Modular systems	ICTs as an innovative tool
Remaining problems	Science is not the dominant epistemic culture This model implies a new economics of R&D	Networks exist but the "selective incentives" mechanisms are not being well understood	Shifting from static sets of modules (static nature of curriculum) to evolutionary structures	"Easy assimilation problem" ICTs have not generated "creative destruction" and remain in the periphery
Policy issues	Creating virtuous circles between "useful R&D", increasing funding, building research capacities leading to more effective R&D..	Supporting horizontal systems of innovation by promoting the private/collective innovation model	Promoting innovation and decentralised initiatives while maintaining general integration and coherence	Creating a "demand side" of the technology equation

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CHAPTER 3
THE PUBLIC DIMENSION OF KNOWLEDGE AND INNOVATION

This chapter discusses the importance of the public dimensions of a knowledge-driven economy. It starts by showing that many key assets in the knowledge economy have some of the peculiar features of public goods. It examines, then, the importance of a "shared collection of basic knowledge" as providing the building-blocks of innovation, in the context of the four drivers of innovation reviewed in the previous chapter. Yet there are contrary pressures for the privatisation of knowledge. This chapter considers how these factors play out, in general and in the education sector. It finishes by envisaging a "bad scenario" in which this public dimension is neglected in educational innovation.

3.1. Introduction

This chapter discusses the importance of the public dimensions of a knowledge-driving economy. It departs from a more usual emphasis today on the role of market competition, particularly in the advancing of ICT-based investment in the "information society". It also balances a preoccupation, in "knowledge management" literature, with how private actors can "capture" information and how businesses can control strategic knowledge assets. In fact, it can be argued that public infrastructure elements of national innovation systems, and their capacity to distribute knowledge, are at least as important over the long run as the direct incentives and subsidies that most governments have been providing to encourage private company investments in R&D (this argument has previously been made in David and Foray, 1995).

The depth studies on open source software, the pharmaceutical industry, the LAM and the public versus private access to databases are extensively used in this chapter.

3.2. The fundamental public aspect of the knowledge economy

Many key assets in the knowledge economy have some of the peculiar features of public goods. This is true in particular of knowledge that can be formulated and made widely accessible (for example through libraries or databases), allowing many people to use them simultaneously. Such knowledge can require high fixed costs to produce but negligible marginal costs to reproduce. Moreover, excluding people from access can bear significant (private or social) costs. The main implication of those attributes is that competitive markets cannot be relied upon to allocate such public goods efficiently, which argues against unregulated privatisation of provision.

The public character of the knowledge economy needs to be well understood, at a time when in practice the knowledge economy is increasingly oriented towards an unbridled privatisation of many parts of the public sector. In particular, there is an urgent need to reconsider how to achieve a balance between the social objective of ensuring efficient use of knowledge, once it has been produced, and the need to provide proper incentives to private producers.

Public knowledge and the four innovation pumps

Within each of the four modes of innovation identified in Chapter 2, this section considers the *public-goods dimensions* of resource allocation, in order to provide some policy guidance for decision making in the public sector, as well as in the sphere of private business. In each of the forms described (science-based, user-based, modularity-based and ICTs-based), the existence of a freely accessible stock of knowledge is crucial. The efficiency of innovation processes is fundamentally dependent on this domain of "public" knowledge and information. By public domain we do not necessarily mean the public sector, or "controlled by the state". We are referring more generally to areas in which knowledge is shielded from mechanisms of private appropriation and in which knowledge and information are revealed and shared.

Science-based innovation

The public dimension of this first source of innovation is very clear. Knowledge resulting from basic research is generic and fundamental. Accordingly, its "social returns" will be far higher if it can be used by multiple innovators. The free circulation of this knowledge facilitates cumulative research, increases opportunities for innovation, and enhances the quality of results (since everyone can examine them and try to reproduce them). This free circulation is at the heart of the organisation model of science, which historically has proved efficient. In this model, the public sector of scientific research produces public knowledge, which can be used freely by industry. This pool of knowledge is an extremely important input for private R&D and innovation. It is generally considered that the existence of public knowledge generates (at least within a specific field) a net increase in private returns to investments in R&D. That is to say, the disadvantages of one's competitors having equal access to open knowledge are on average exceeded by the advantages of this common body of knowledge to companies investing in further research.

User-based innovation

The public dimension is a necessary condition for the functioning of communities of users. In these communities, multiple potential sources of innovation are activated and each member of the community can benefit from them. If this condition were not met, each user would be obliged to make all the adjustments to a technology or process required by a particular strand of innovation, which would substantially increase the overall cost of the system. It would consequently have no chance of competing with lower-cost solutions designed to meet the needs of the "average" user, produced by commercial systems. The sharing and circulation of innovation is therefore essential to ensure a minimum of efficiency.

Modularity-based innovation

The public dimension of this third source of innovation is less known but equally clear. It results from the collective creation of quasi-public goods in private markets. It is essential to preserve public access and the sharing of "essential" technological or informational elements composing the norm, standard or infratechnology of an industry. As emphasised in the case study on microelectronics (summarised in Box 2.2 above), this industry is characterised by a "surprisingly cooperative attitude of firms". This arises primarily as a result of private and social benefits generated by: *i)* a co-operatively constructed common technological ground; *ii)* universal adoption of the same dedicated pieces of equipment and; *iii)* the creation of interface standards to promote the re-use of modules in various systems. As in the preceding cases, this poses thorny problems of compromise between the collective aspect of innovation and the safeguarding of private interests.

ICT-based innovation

ICT may be defined as a technological field where inventions have a strongly cumulative value. This is, for example, the case of the production of software, which can be built up from combinations of modular sub-processes that have been previously tested and shown to be interoperable. Software programmers tend to rely heavily on the work of their predecessors. It is usual for programmers, when confronting problems that have been addressed before, not merely to learn from the solutions developed by their predecessors, but to copy those solutions verbatim. Recent trends in copyright and patent law threaten that socially efficient practice, by making sharing more difficult. At the same time, development of the voluntary open source model is providing evidence that private appropriation of software codes is not the only way of sustaining innovation and growth in this sector. The provision of economic incentives that encourage people to reveal their knowledge freely seems to be more consistent with the cumulative nature of knowledge in that field.

Thus, a continuous supply of public knowledge through each of the four "pumps" described above is needed to ensure that innovation continues to flow freely. The shared collection of basic knowledge is an essential lubricant that helps prevent the innovation process from becoming congealed or blocked.

The public sector role in creating a "knowledge infrastructure"

In modern economies, the public sector occupies a variety of prominent, institutionalised roles in the creation of knowledge infrastructures that support innovation activities. In some instances, this has been the result of deliberate (rational) institutional design. Elsewhere, non-market modes of resource allocation that may have originally been created to further private interests, or to serve the ends of state power, have proved themselves able to survive in the face of challenges posed by fallible market mechanisms. Hence, it is hardly surprising that many commentators are now looking to the public sector to provide critical services enhancing scientific, technological and economic capabilities of modern societies through a strong infrastructure supporting innovation. Such services can include formal educational instruction, the creation and maintenance of archives, libraries and technical reference systems, the conduct of exploratory (so-called "basic") research activities, the codification of technical specifications or standards of commodities and the delineation and enforcement of monopoly rights in intellectual property.

The progress of information technologies clearly helps drive innovation, for example by facilitating the dissemination of learning systems and allowing distant collaboration in research. Yet it also creates some areas of tension which public knowledge infrastructures need to help deal with. These cannot be discussed fully here, but the following subsection highlights a particular difficulty.

Information superfluity and the problems of "attention management"

Modern economies are converging towards the extreme condition described by the Nobel Laureate economist, Herbert Simon, who envisaged a world in which information had become super-abundant and attention was the scarce, constraining resource. The abundance of information is now combining with the increasing dispersion of the sites at which information is distributed: the growing army of knowledge-producers create a huge information stockpile through which it is very hard to manoeuvre. A key difficulty is locating and distinguishing useful information.

To avert the problem of being unable to retrieve critical information, private enterprises have invested in sophisticated indexing and data retrieval software, in high-speed search capabilities and in filtering and other selective, attention preserving techniques. Without efficient search capabilities, the private cost of congestion (information overload) would overcome the benefits provided by information abundance.

Yet here again private efforts to tackle the problem alone will create a sub-optimal solution. The public good issue is created in particular by the fact that the feasibility of information search is strongly influenced by the ways in which other people store, codify and signal information. The more that this is standardised rather than idiosyncratic the easier the search process. Thus, the public sector has a role in infrastructure investments in archiving, standard dictionaries, classification systems, and the like, all of which would contribute to reducing the variable costs of search, yet which tend to be under-funded by the private sector.

A critical role that the public sector has to play here is in reinforcing the traditional function of libraries, archives and museums in making knowledge widely and publicly accessible (see Box 1.2 above). In particular, they will in the future be a protection against opposite tendencies, such as restricting access to a privileged minority with privately owned search tools, and also the privatisation of knowledge itself.

Databases: in search of the free flow of information

In his case study for this project (see Box 3.1), Uhlir defines databases as a collective tool for research and education. This is why there is a particular concern when exclusive rights are assigned to databases (such as the mechanisms involved in the provision of the EC's Directive for the Legal Protection of Data Bases). A database can be defined as an information space constituting a dynamic collective research tool. According to the Director of the European Bioinformatic Institute, discoveries in many domains are made in the course of *unplanned journeys through such information space*. If that space is restricted by a host of property rights, the journey will become expensive (if not impossible) and the knowledge base itself will suddenly be found to be shrinking. This is a danger with the granting of rights by the EC's Directive for the Legal Protection of Data Bases: allowing providers to extract licensing fees from users might reduce the chance of unexpected discoveries. Targeted searches may be quite affordable, but wholesale extraction of the data spaces' content to permit exploratory search activities is especially likely to be curtailed (David, 2001).

Box 3.1. Open or closed government information in a post-Cold War, technological era? – Some key points from Uhlir's depth study*

Governments need to think about what they can contribute to the pursuit of science by providing openly accessible data, and more generally about how open they should make information in an era where technology has allowed databases to become accessible from everyone's computer.

Since the end of the Cold War, there have been considerable pressures to open up information to the public, although this has been countered to a considerable extent by the growing security considerations linked to terrorism. At the same time, commercial pressures combined with a privatisation of information production in some cases have caused governments to consider a more restrictive attitude.

One thing that causes governments to sell some information is to help pay for the cost of its production and dissemination. Another is pressure from commercial interests, felt not just through direct lobbying but also through international agreements (*e.g.* through the World Trade Organisation) to protect intellectual property. This has contributed to considerable restrictiveness. Even in jurisdictions or information domains where restriction of public information resources is not allowed, increased legal protection has indirectly reduced access to government information by increasing incentives for the private sector to gain control over those public resources for profit. Yet the logic of open access to government information remains: governments do not need a commercial incentive to produce information; the benefit of openness goes to the citizens (taxpayers) who have funded its production; openness enhances democracy; and it brings positive externalities.

This paper illustrates the benefits of openness and the short-sightedness of restriction, by contrasting US and EU meteorological services, the former more open, the latter more commercially oriented. It argues that a public body operating commercially in the latter case simply combines the inefficiencies of a subsidised public monopoly with countless lost social gains associated with its commercial treatment of information.

Full study paper: "New Models of Information Production and Management in Public Research: Legal, Economic and Science Policy Considerations", by Paul F. Uhlir, *www.oecd.org/edu/km/mappinginnovation*

3.3. The privatisation of knowledge? General trends and specific worries for education

The education sector is vulnerable to pressures to privatise knowledge. This section starts by describing at a general level how these pressures are playing out, and later looks at the particular case of education.

Privatising intellectual property

The new salience of "knowledge" as an economic asset has led to a strengthening of intellectual property protections, which has in turn contributed to two problems (exacerbating existing difficulties) for the research and educational community. The first is the rising cost of exploratory research activity conducted by communities of open science researchers. This has been hindered by patenting of basic scientific techniques. Public funding for "open" scientific enquiry does not adjust upwards automatically to offset those extra costs, and extensions of legal protection for databases threaten to impede the use of large and complex "information spaces" and the specialised search engines that have been created to explore these.

The second difficulty has been the deterring of innovative new entrants to scientific and commercial innovation. A shifting of attitudes in business and government circles toward greater reliance upon the protection of intellectual property as an inducement to knowledge creation has led companies to invest in the commercialisation of new discoveries and inventions.

As part of a trade deal hammered out eight years ago, countries joining the World Trade Organisation also sign up to TRIPS (trade-related aspects of intellectual property rights), an international agreement that sets out minimum standards for the legal protection of intellectual property. TRIPS can be viewed as the institutional adjustment at the international level to the increasing role and importance of intellectual property rights in the knowledge economy. That raises critical issues in terms of access to vital resources in sectors like health and education.

Those countries that have signed up to TRIPS have accepted international copyright and patent rules. Although these allow some unauthorised copying for "fair use" or personal consumption for services like education, many experts[1] worry

1. For example, the Commission on Intellectual Property Rights (IPR) convened by Britain's Department for International Development to look at the impact on the IPR rules on the poorest countries.

that these exceptions are too limited (see Box 3.3), and that copyright and patent may hamper access to textbooks, journals and other educational material in poor countries, by requiring the consent of, and likely payment to, the IPR holder prior to copying. Experts are even more worried about the Internet, which has great potential for broadening access to education in poor countries, but in which encryption technologies can override the principle of fair use.

Principles for a patent system – complexity and a loss of consensus

Economists typically consider the patent system as a necessary evil (Hall, 2002): innovation will benefit from the incentive created by a patent but it may suffer if patents discourage the combining and recombining of inventions to make new products and processes. Thus the relationship between patents and innovation is guaranteed to be a complex one, and one that may vary over time and across industries.

Economists had nevertheless reached some kind of consensus about twenty years ago: that the patent system was a good thing for innovation and growth, provided its negative effects on the economy were reduced. In this respect, very simple rules need to be applied: a) the requirement that a technical description of the invention maintains a balance between the inventor's private interests and the interests of society; b) the exclusion of science, research and education from the domain of patentability through criteria of industrial application; and, c) application of the criterion of inventive activity to delineate clearly the areas of human activity that can be appropriated by a patent.

However, this consensus has collapsed for four reasons:

- Abuse of all kinds has spread, related to ways in which patents are used: a massive quantitative jump in the number of patents filed (exceeding 300 000 annually in the US); patents "moving up" to domains of scientific research; and amendment of the rule of technical description due to the fact that it cannot be complied with in the case of certain new objects even though they are considered patentable (*e.g.* genetic creations or software). Thus, the rules to limit negative effects are not properly observed and consequently fail to do their job of regulating the system.

- Economists are realising that other incentive mechanisms can efficiently support innovation without creating effects of exclusivity and monopoly power. A case in point is open source, illustrated in von Hippel's depth study (Box 1.1 above). This example can be used to verify and control real processes of support for innovation, based on open knowledge.

These first two reasons indicate that what may once have been regarded as the "necessary evil" of a constrained patent system has, with a loosening of constraints, become simultaneously a greater evil and one that can no longer be defended as wholly necessary:

- Patents are now affecting vital activities – most obviously health but also education (see Box 3.2). While a patent on a new type of ball bearing shocks no one, the same cannot be said for a new patent on a drug, diagnostic test or educational method.
- The basic mechanisms aiming at maintaining free access to patented knowledge (for example exempting research or educational goals) only provide a fragile legal basis. The recent case of Madey (see Box 3.3) shows that the research exemption might no longer be a reliable device in the future.

Box 3.2. **US examples of patents for education and instruction techniques**

The number of patents granted under this classification by the United States Patent and Trademark Office (USPTO) has more than doubled in two decades, from 123 in 1981 to 288 in 2000. Recent examples include:

- USPTO: 5 851 117, 1998 (granted): *Building Block Training Systems and Training Methods*: the patent describes how an experienced person can teach a novice by using an illustrated publication, such as a training manual.
- USPTO 6 322 367, 2001 (granted): *Method and materials for teaching the phonetic code and repairing self-esteem*: This invention of materials and method is designed for assessment of phonetic reading ability and for teaching the phonetic reading code to children and adults of average intelligence and abilities who have responded poorly to traditional reading instructional methods or who choose not to be limited by methods of reading dependent on memorisation of words.
- USPTO 6 341 960, 2002 (granted): *Methods and apparatus for distance learning based on networked cognitive agents*: The Intelligent Tutoring System (ITS) uses the Internet as a constructivist learning environment and aims to provide intelligent assistance to improve both quality of training and distribution of knowledge in a distance learning situation.
- USPTO 6 343 319, 2002 (granted): *Method and system for curriculum delivery:* A computerised curriculum capture, organisation and delivery system is provided, including a data gathering mechanism for defining and downloading a quantity of data from a data source.

Box 3.3. **The fragile legal basis of "fair use" exceptions for research and education**

The research and education exemption, which provides free access to patented knowledge for educational and research purposes, is becoming an uncertain mechanism whose legal force is weakening.

The 2002 Federal Circuit Court of Appeals case of Madey v. Duke University emphasises that most basic science and higher education conducted in US universities is ineligible for this exception. Madey, a former laboratory director at Duke University, sued the university for infringement of patents on free-electron lasers and their use, which he had taken out prior to working at the university. The appeal court upheld the claim, despite the university's argument that as a non-profit educational establishment its activities were not subject to patent infringement as long as they were solely for research, academic or experimental purposes

The court's decision showed that, because basic research and higher education must be considered as "the core business of a university", the criterion of an activity undertaken for "amusement, to satisfy idle curiosity or for strictly philosophical inquiry" (which is at the base of the exception) does not apply here. In the case of universities, "business" includes any research that furthers "the institutional objectives of educating and enlightening students and faculty". The profit or non-profit status of an institution is irrelevant to this determination.

The Madey case makes clear that educational purpose is not a legal basis for free access to patented knowledge and materials because the business objectives of universities and schools are related to these educational purposes. This case may open the eyes of knowledge users including educational officials to a source of liability that they did not previously consider.

The production and patenting of knowledge "tools"

One potential development that could transform the structure of knowledge ownership in education is the emergence of companies specialising in making the "tools" for knowledge production. As a precedent, in the pharmaceutical industry, the 1990s saw the emergence of enterprises seeking to develop and patent biotechnology knowledge such as DNA sequences, and to sell these techniques to drug companies involved in their actual application to products (see Cockburn's depth study, Box 3.4). A parallel from the past is the emergence of specialised machinery and tool companies in the 19th century; a parallel from the future could be a multiplication of educational enterprises devoted to developing, patenting and selling particular instructional techniques. Already, as described in Box 3.2 above, hundreds of educational patents have been registered and educational "tools" companies exist, but serious restriction of access to fundamental and applied knowledge in this sector, if it ever occurs, is still a long way off.

Box 3.4. **Patenting the genome and the emergence of biotechnology "tools" companies – some key points from Cockburn's depth study***

The way in which the bio-technology industry applies scientific knowledge has changed profoundly in the past two decades, and with it the structure of this industry. Broadly speaking, in the 1980s large drug companies used their own R&D capacity to apply scientific knowledge in ways that allowed them to develop new products, while pure science was conducted in the non-profit, largely university sector. The 1990s saw a "vertical disintegration" in these functions, as smaller companies started up purely to develop technological "tools" that allow the main product companies to develop and produce drugs. Such tools encompass highly advanced scientific knowledge related for example to the genome, and are sold on license to the large drug companies. The tool companies operate at the interface between industry and academe, and sometimes blur the distinction between the two, since their staple input is highly advanced scientific knowledge.

This change has been accompanied by a new style in the use of patents. The product companies continue to use patents largely as protection against imitation by direct competitors. The tool companies seek broader patents on data and methods, and aim to use complex contractual arrangements to charge product developers fees for their eventual use in a range of end products. Typically, they secure such arrangements through their power to block the use of novel methods or newly acquired bio-tech data.

This paper explores the complex process of vertical disintegration that has been involved in the transformation. It concludes that while the overall impact has been mixed, the experience has demonstrated ways in which such a process can have a range of inefficient features. In particular, contractual arrangements become very complicated, and much energy is expended on finding workable ways of assigning the commercial benefits between the "tool" and "product" companies. In the short term, a flood of patent applications has put such intense pressure on the patent office that the quality of examination of patents risks being compromised. In the longer term, the impact of extending the domain of patents deeper into the sphere of pure research could be very serious – but to what extent, it is too early to evaluate.

Full study paper: "Open Science, the Intellectual Commons, and the Productivity of the Biomedical-industrial Complex" by Iain M. Cockburn, *www.oecd.org/edu/km/mappinginnovation*

Cockburn's depth study gives a chance to compare a "vertically integrated" applied sector operating alongside a non-profit making academic research community (the previous model in the pharmaceutical sector) with a "vertical disintegration" at the interface between industrial production and science, centred around the highly knowledge-intensive, science-driven but commercial tool companies. The efficiency of previous vertical disintegration, such as the case of companies producing physical machinery and tools in the industrial age, relied on several conditions: strong competition among such companies themselves; specialisation to reduce costs; prices that reflect marginal costs; and simple and efficient contractual arrangements. In the case of specialised production of R&D tools, the latter two conditions are not met. In particular, as Cockburn points out, such arrangements are highly complex and commercial and contractual arrangements become problematic.

Moreover, unlike the 19th-century tool companies, enterprises producing knowledge tools rely on their income on patents and exclusivity rights to generic knowledge. These can create high social costs for the system. For example by creating monopolies on the exploitation of research tools, the generic and cumulative value of which is thus lost. The system is deprived of potential benefits generated when several firms with different capacities and perceptions of a problem are mobilised. A patent-based system can also increase delays in knowledge development and raise costs involved in negotiation and litigation.

However, the experience so far shows that the market has so many shortcomings in the area of basic research (uncertainty and difficulty in appropriating knowledge, despite the use of patents) that commercial success is rare. This reflects what Nelson (1959) called "the simple economics of basic research". As argued by Cockburn in his study: "patents or no patents, capturing value that ultimately derives from fundamental early stage is extraordinarily difficult for profit-oriented organisations". Anecdotal evidence and the relatively low stock market returns from research tool companies support this pessimistic view.

Copyright and patent in education as the next battleground?

The data in Box 3.2 above illustrate the constant increase of patent application and grant on educational methods. Many experts believe that education will be the next battleground in terms of intellectual property. A number of factors appear to support this argument.

The combination between the increasing use of ICTs in schools and the development of real R&D processes (experimentation and RTC) to control the effectiveness of ICTs as an educational tool is likely to produce extremely valuable knowledge concerning educational methods. At the same time, ICTs are starting to empower a set of new instructional providers who might compete with conventional public schools. Such technology-enabled competition might have many virtues in propelling improvements by all providers. For example, if twelfth grade students had an option widely available to them of completing Advanced Placement or community college level courses on line, perhaps from a private provider, and not attending their regular high school, public schools may be encouraged to compete in developing such advanced provision to preserve their enrolment-based tuition revenues.

Yet at the same time, such market competition would dramatically increase the commercial value of some kinds of instructional knowledge, whose production and commercial exploitation may be the basis of a new business model. A possible outcome would be the emergence of "educational tool companies" at the interface between public educational research and schools. These companies would heavily rely on patenting educational methods in order to generate income by granting licenses to schools. If this mirrored the pharmaceutical sector developments described by Cockburn, a proliferation of patents could impose heavy social costs on the system. Is it a totally absurd scenario? Time will tell.

This kind of problem has an "elegant" solution – meaning a solution which enhances social welfare as measured by economists. Textbooks call it "price discrimination" – a distinction between users who are sensitive to price changes and those who are less so. The latter category of buyer will bear high prices without curtailing the quantity of goods purchased, whereas the market will offer low prices to those in the first category (*e.g.* scholars and university-based researchers) which will spare them the burden of cutbacks in their use of the good (David, 2001). Economic theory suggests, therefore, that such discrimination can enhance social welfare if the infringement, which is tolerated, does not reduce the value of the resources for users who are prepared to pay for access to it.

3.4. Conclusion: three E's in support of the revival of public property

"If national patent laws did not exist", wrote Edith Penrose over forty years ago, "it would be difficult to make a conclusive case for introducing them, but the fact that they do exist shifts the burden of the proof and it is equally difficult to make a really conclusive case for abolishing them." (Penrose, 1951). This argument is useful if we consider that certain sectors of the knowledge economy are still exempt from the mechanisms of private appropriation of knowledge through patents. In the education sector, although hundreds of patents have been registered, the patent does not exist in the sense that it does not constitute a fundamental reason for economic agents' entry into the market. In other words, it is not a decisive element shaping these agents' expectations of possible private gains from innovation in this sector. In this case, Penrose's conclusion seems attractive: it is difficult to make a conclusive case for introducing national patent laws.

It is crucial to note that the scientific revolution underway has unequalled potential to produce tools for development fields as diverse as agriculture, health and education. But this scientific revolution is historically the first to be essentially private, a situation that generates problems of access to and acquisition of knowledge, as well as problems of priorities in research programmes.

Many policy-oriented works are now devoted to regulations that the intellectual property system must implement to control its own excesses. This is a crucial issue. Patent policy is extremely important in opening new fields of commercial opportunities. When research results become patentable, as a result of Court and patent office decisions, expected private profitability increases substantially and many activities can be taken care of by the private sector. That is typically the case today in many areas of life sciences. Thus, a sensitive and controlled patent policy is a key to regulating the tendency towards privatisation.

But it is also a matter of a revival of public property. It is therefore important to reformulate the rationale supporting public property in the generation of invention and innovation and the provision of the knowledge infrastructure. Three principal categories of public action which are generically relevant in promoting the socially efficient production and use of knowledge can be identified, and labelled the three "E's".

Externalities

The first category of actions which falls largely to the public sector to design and implement involves the subsidy or direct provision of some of the critical public goods in the knowledge-based economy. There is a clear economic rationale for public intervention where competitive markets are expected to do a particularly bad job in producing and distributing knowledge and information. Salient cases involve exploratory science, and R&D that is expected to yield very substantial knowledge and learning externalities – such as access to training and learning for the unemployed (including jobless young people, and older workers), the provision and support of information infrastructures, and so forth. One important part of basic research has to be carried out under an open principle: providing an effective mechanism for ensuring fast and extensive dissemination of new knowledge. Today more than ever, standards of conduct regarding the disclosure and efficient distribution of knowledge should be top priorities in scientific research and educational services.

Equity

The second type of public action involves the optimal use of knowledge for the benefit of future generations and for protecting the well-being of certain non-solvent consumers, *i.e.*, those without financial resources to purchase critical goods, such as drugs to combat infectious diseases or new educational methods. Many issues related to finding "equitable solutions" to difficult problems of resource allocation among research "priorities" fall into this category. Private markets tend to under-fund projects targeted to the needs (or simply the tastes) of social minorities, as well as the low-income, developing economies. Generating and disseminating knowledge that is relevant to solving problems affecting the welfare of future generation is therefore an important societal objective. Future generations have the right to demand a "knowledge legacy", just as we currently benefit from knowledge produced by past generations. But these are not tasks that the private sector can be expected to perform unassisted.

Expertise

A final category of action involves the provision of conditions in society that nurture the formation of independent communities of "expertise" in complex scientific, technological and possibly also cultural matters such as historical studies and the arts. It is unrealistic to expect profit-seeking private entities that must survive in competitive markets to subsidise the work of communities of experts whose opinions cannot be controlled and who might reach conclusions that adversely affect an "altruistic" business sponsor, or benefit a rival company. An obvious difficulty in this area, however, is that the same mechanisms to control the pronouncements made by expert authorities on matters of a controversial political nature may exist in government circles as well. Sources of independent expertise are thus a form of public good that governments are unlikely to be able to supply by means of direct provision.

Subsidies for commercially oriented private producers, or procurement contracting by the public sector, are important alternatives that can co-exist with direct public production of public goods. Moreover, there are forms of "inherently public property" which are controlled neither by government nor by private agents, in particular those based on voluntary collaboration between knowledge producers and users. It is probably this category of public property that constitutes the framework for the revival of the public domain in the context of knowledge-based economies, since that is where the knowledge communities described in the von Hippel and Cockburn studies may be found, from open science to all the modes of collective production set up by users.

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CONCLUSION

The knowledge economy is one in which innovation is becoming the dominant activity. The capacity to innovate helps determine not just winners and losers in competitive markets, but the degree to which each economic sector progresses and realises its potential. This is true of not just of private commercial activities and industries, but also of sectors that continue to be delivered primarily by public organisations, such as education.

Of course, innovation and the progression of knowledge are nothing new. What the recent experience of innovation in various sectors explored in this report has shown, however, is that today there is potential for innovation through a range of modes, not all of which were available in the past. Advances in information and computing science and technology have allowed scientific knowledge to be developed and disseminated at an accelerated pace. They have also permitted the proliferation of new innovation modes based on complex interactions among users/practitioners and the modular development of knowledge within an industrial system, rather than on a simple linear transfer of technology from scientists to system controllers to practitioners. New information and communication technologies in some cases drive innovation, but more importantly they provide the means for a range of interactions that make new types of innovation possible.

These developments provide an immense opportunity for education systems, even if they do not produce a ready-made and fully transferable innovation model. There are many particularities of sectors such as microelectronics and biotechnology as applied sciences, not all of which are shared by the science of education. Nevertheless, educational policy makers can learn much from observing how innovation occurs and how sectors are transformed in the most knowledge intensive parts of the economy. A prominent Irish chief executive[1] recently reflected that one of the most important such lessons may come from observing the ability of businesses to "reinvent themselves" in the face of globalisation. Education, it is

1. Sean Dogan, Chief Executive Officer, IDA Ireland, opening OECD meeting of education chief executives, Dublin February 2003.

clear, is not about to reinvent itself, but how much can educators learn from the trends and opportunities outlined in this report?

This question will need to be answered on a case by case basis by individual policy makers operating in various contexts. Not each of the four innovation "pumps" described in Chapter 2 will be equally relevant to every aspect of educational innovation. The important thing is to be aware of the potential of these pumps and to explore their applicability to each case. In particular, policy makers should not neglect the potential usefulness of such forces of innovation, or the way in which they can be optimised by creating the right incentives (*e.g.* among users to participate in innovation) and organisational structures (*e.g.* to legitimise "modular" innovation and to enable it to contribute to the improvement of the whole educational system).

Thus it is important as a first step to recognise these four forces of innovation – scientific advance, user-based networks, modularity and information and communication technologies – and to recognise the ways in which the education sector has been neglecting their potential. However, simply acknowledging their existence is not enough. As Professor David Hargreaves has pointed out (see Box 2.6 above), some imaginative and courageous leadership will be needed if education systems are to change their orientation sufficiently to unleash forces that drive *transformational* rather than just piecemeal improvements.

In particular, this implies a fundamental change in the place of scientific research and development in relation to educational innovation. The track record of the "linear" model of advances in scientific knowledge driving change in educational practice has not been a strong one. It has simply not been possible for the educational "laboratory" to produce sufficiently robust evidence on a range of educational topics to provide guidelines for change to systems. A more diffuse model of knowledge production, involving practitioners themselves more directly, may ensure that the knowledge produced has a more pervasive influence on practice than that which is handed down from universities.

However, it should not be assumed that all changes in the norms of knowledge production and innovation are necessarily for the best. Chapter 3 above has highlighted the potential for certain new innovation modes to create an undesirable level of privatisation of knowledge. Specifically, the education sector may take a cautionary lesson from the experience in the pharmaceutical sector of the emergence of "tool companies" specialising in the development of techniques that they are keen to patent. In education, too, such firms are emerging, which rely heavily on patenting innovation to seek returns from selling educational methods. These companies, which assume the role of specialist suppliers of leading edge methods and technologies, may seriously hamper the public dimension of educational research and innovation.

Thus, the big “innovation policy challenge” will be to steer an optimised path between increasing the effectiveness of innovation processes and maintaining its public dimension. Improved effectiveness may require increased funding of research, the implementation of new R&D methods and the involvement of companies developing and testing instructional knowledge. The public dimension is defined as a “knowledge area” that is shielded from mechanisms of private appropriation, and in which knowledge and information are freely revealed and actively shared. Finding the proper conditions for optimising this path constitutes an important agenda for future research.

Two decades of works on innovation by economists show for example that national specificities matter a lot in finding the proper conditions for innovation (Lundvall, 1992; Nelson, 1993; Edquist, 1998). The concept of a national innovation system helps to explain why certain clusters of institutions strongly influence innovation strategies and performance in each country. Such national innovation systems can be expected to exist in education too. A more systematic comparison of national systems of educational innovation would be needed to map innovation using the four pumps at national level, to highlight national strengths and weaknesses (OECD, 2003). In some countries, regional differences will also be relevant.

More than sixty years ago, Joseph Schumpeter (1939) observed the economic importance of clusters of innovation and postulated that the creation of new or improved product, process or organisation is a more devastating form of competition than non-innovative competition. Most sectors and industries in the knowledge economy are currently experiencing a "Schumpeterian renaissance" (Freeman, 2003): innovation is today the crucial source of effective competition, of economic development and the transformation of society. Does this renaissance extend to the education sector? The answer must be “not yet”, to the extent that efforts to implement change in the name of “educational improvement” have aimed mainly to raise the effectiveness of the system at the margin without trying to move the system into a new era. It is time now for all stakeholders in education systems to consider seriously the principles of the Schumpeterian renaissance in relation to the organisation and evolution of educational activities, and to design policy actions accordingly.

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