The development of knowledge of different sectors:

a model and some hypotheses

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1. What are the new challenges facing the knowledge economy today?

While knowledge has always been at the heart of economic development, there is substantial evidence that the capacity to produce and use knowledge has much more explanatory value in explaining levels of economic welfare or rates of growth than in the past. Factors determining the success of firms and national economies are more dependent than ever on the capacity to produce and use knowledge. The other side of this new aspect of economic growth is that innovation and technological changes have become more central to economic performance (Foray and Lundvall, 1996, OECD, 2000).

This is not to say however that such a tendency affects the whole economy in the same way. On the contrary, one can observe a strongly unbalanced and uneven development of knowledge across sectors and fields. Advances in human know-how have been spectacular in some sectors such as ICTs, remarkable in dealing with some kinds of human illness but very limited in other areas, for example education, managerial know-how, avoiding wars, developing cities (Nelson, 2000). A major policy concern is to understand the factors that are at the origin of such uneven development and to implement a proper strategy in order to fill the gap between the sectors with fast knowledge accumulation processes and the sectors where these processes remain weak. The education sector is a good example of a sector characterised by a slow process of knowledge creation and diffusion about teaching, and this stands in contrast with some other sectors like ICTs, transport or biotechnology.

In the second section, we develop a framework to identify a "model" which supports rapid human know-how creation and accumulation in sectors like ICTs, pharmaceuticals, aeronautical engineering. This model is a combination of two basic parameters: the first deals with a certain kind of "science and technology interface", described by Nelson as a "strong science that illuminates technology"; the second one is related to the notion of competitive environment and knowledge spillovers, as influencing the level of private incentives for innovation. In the third section, we show why the traditional modes of knowledge creation and diffusion in the education sector does not fit the model described above. The final section examines a national example of a developmental trajectory aiming at improving the mode of knowledge creation and diffusion in the education sector. This case is analysed through a comparison with the historical trajectory of the mode of knowledge creation and diffusion in medicine. The nature of the knowledge base in this sector has changed dramatically over the last century and it is interesting to explore to what extent the nature of the knowledge base in the education sector can change in a such great order of magnitude.

2. Why is there unbalanced development of knowledge across sectors and fields?

In this section, we identify two factors that seem to be of critical importance in shaping the way knowledge is created and accumulated. We thus build a model which may be viewed as a heuristic device to help understand how the education sector might be transformed in order to obtain a more rapid and effective trajectory of knowledge development.

2.1. On the science-technology interface

A first set of factors enable rapid knowledge creation and accumulation in a particular field (Nelson, 2000). These deal with the interface between science and technology and include:

- "*A strong body of understanding that enables effort to advance a technology to reach significantly beyond the current state of the art before getting into areas where probing is completely blind*" (Nelson, 2000). This issue has been addressed previously by Kline and Rosenberg (1986) who provided a clear classification of the various stages of science as affecting the cost and time requirements of knowledge advances. "*In the earliest stage the work in a science is descriptive; in the next stage the work becomes taxonomic; then the work passes to formation of generalizing rules and hypotheses and finally, in some sciences, to the construction of predictive models*". Only science in the predictive stage provides results, which are usable immediately to advance technological knowledge. A science still in the earliest stages is far less valuable for these purposes; although it can play an important role in guiding the innovative work.

- The second factor mentioned by Nelson (2000) deals with the ability to conceive and carry out well defined and controlled experimental probes of possible ways to improve technological performance; and ability to get relatively sharp and quick feedback on the results. Well-defined and controlled experimental probes are required to isolate the technology from its surroundings. Experimentation is often carried out using simplified versions (models) of the object to be tested and of the environment (Thomke et al., 1998).

Both factors are at the basis of "*a strong science that illuminates technology*" (Nelson, 2000). Such a model of "science illuminating technology" (S-i-T) includes the following features: experimentation in the development of science[1]; strong linkages and feedback loops between the development of science and the advance of technology; most of the inventing goes off line (in the R&D labs); an important part of the knowledge base is codified in instructional guides and documentation, providing an effective way for transferring knowledge from science to technology and practices.

In this model one should also appreciate the feedback loops from advances in technology (instruments) reducing the costs of and opening new fields in basic research. Thus this is a complex of interdependent dynamics, *science illuminating technology and technology equipping science*, which is at the origin of a rapid accumulation of knowledge in some sectors. However, such a model may not work in

[1] - Although Nelson does recognize that some sciences are not experimental, he is right to point out that most of the strong fields of empirical science have involved experiments in an essential way.

all sectors, and so there is the question of what alternative model may be needed to support rapid knowledge creation in other sectors.

In some sectors, indeed, the main source of knowledge is related to some kind of "learning-by-doing" effects[2], where individuals learn through activity and, as a rule, can assess what they learn and hone their practices for what follows next. In this context R&D, as usually defined, is not of immediate value for developing applications and practical knowledge. In such cases, advances in know-how are not dependent on scientific progresses but on the ability to fully exploit the opportunities offered by learning-by-doing. 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 on the field and not in the R&D laboratory. This 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. 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. The regular activity must continue while the learning takes place. In this context, learning is a joint activity and the creation of knowledge a joint product. Knowledge creation is not the intentional goal but may nevertheless occur as a by-product of the activity.

There is, therefore, a tension between the normal performance and the learning aspect. "*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, 1998).

Beyond the generic form of learning-by-doing, it is important to differentiate two levels. A first level of learning-by-doing is essentially based on repetition and on the associated incremental development of expertise: by repeating a task, I become more effective in executing this task. It consists of procedures of routine adaptation and leaves no room for explicit evaluation, codification and exploitation of what has been learned.

Another level of learning-by-doing is explicitly cognitive. It consists of performing experiments during the production of goods or the provision of services. 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 expertise produced through this explicitly cognitive learning-by-doing does not, however, constitute scientific knowledge in the sense of the S-i-T model and the locus of the learning process is not the R&D lab but the manufacturing plant or usage site or the class room. In other words, explicitly cognitive learning-by-doing consists of "on line experiments". Some kind of R&D may play a role in this process, in order to develop methods and techniques to document, assess and promote the innovations emerging from the learning-by-doing process. This does not mean, however, that learning-by-doing is a scientific experiment. It is not for the reasons discussed above.

[2] Learning-by-doing is a form of learning that takes place at the manufacturing (and/or utilization) stage after the product has been designed (i.e. after the learning in the R&D stages has been completed). It leads to many kind of productivity improvements often individually small but cumulatively very large, that can be identified as a result of direct involvement in the productive process. Thus, learning by doing constitutes the basis for a relationship between productive experience (the accumulation of « doing ») and the improvement of productive performance. A learning process takes place and it is argued that this effect is the result of the development of increasing skill in production attained by learning by doing and by using. This is, thus, a source of innovation that is not recognised as a component of the R&D process, and receives no direct expenditures.

In cases in which the learning-by-doing opportunities are well exploited, this model can be an extremely potent form of knowledge creation[3]. However, in most cases know-how advances are slower than in the “science illuminating technology” model.

We have just characterised two models that are different from the point of view of the nature of the knowledge base. While the first “S-I-T” model is strongly influenced by the creation of scientific knowledge which is of direct value to develop process and product innovations, the other model is based on learning processes occurring “on line” (in the plant, on the usage site, in the class room). This model will be called “humanistic”. The two models are not only different in terms of the way knowledge is created. They also differ in the way knowledge is diffused. Scientific knowledge is explicit and codified and, thus, can be transmitted through the media of books and journals.[4] Much humanistic knowledge is tacit and so requires interpersonal interactions, such as coaching and mentoring, if it is to be transferred.

We do not believe that in practice any sector relies on a single model. Even the most “science-based sectors”(e.g. ICTs, biotechnology, new materials) have some new knowledge deriving from learning-by-doing processes. In the same way people-centred professions which strongly rely on the humanistic model may also benefit from scientific knowledge: doctors build up their expertise through a combination of science-generated, explicit knowledge with their own learning-by-doing expertise from work with their own patients. Of course there are strong variations in the relative weights of the two models across sectors.

2.2. Competition and knowledge spillovers

The second factor governing the speed and rate of knowledge development has to do with the competitive environment. The argument is straightforward. Competition promotes innovation: the pace of innovation in most industries is clearly linked to high level of competition there. The simple argument is that innovation (that is the creation of new knowledge and new ideas that are then embodied in products, processes and organisations) allows companies to escape from perfect competition where they are “price taker” by acquiring temporary market power and becoming “price maker”. Competition not only creates incentives to produce new knowledge but it also forces the other agents to increase their own performance through imitation, adoption, absorption of the new knowledge created elsewhere, in order not to be excluded from the market. This encourages economic agents to build and develop absorptive capacities so that involuntary information and knowledge spillovers may increase at the system level. The existence of

[3] - The possibility of moving on to the latter form of learning in activities other than "craft trades" represents an important transition in the historical emergence of the knowledge-based economy (David, 1998). As long as an activity remains fundamentally reliant on learning processes that are procedures of routine adaptation and leave no room for deliberate planning of experiments during economic activity, the difference between those who deliberately produce knowledge and those who use and exploit it remains substantial. When an activity moves on to higher forms of learning where the individual can plan experiments and draw conclusions, knowledge production becomes far more collectively distributed.

[4] - We are aware that such an argument vehicles the risk of over-generalisation: very few research results and scientific inventions are formalized from the start to the point of being a “simple” set of codified instructions so that experiments and results can be reproduced by scrupulously following the codified instructions. In reality, new scientific knowledge are far more often presented as a combination of formalized instructions and tacit knowledge that can be acquired only in the laboratory where the scientific research was carried out. This tacit dimension represents a transitory source of intellectual capital, producing rents for scientists who have the know-how (Zucker and Darby, 1997). However the nature of pecuniary and non pecuniary rewards in scientific research produces strong incentives for knowledge codification, articulation and clarification once it has been created since the rewards accrue from publication and dissemination (Dasgupta and David, 1994).

knowledge spillovers (or involuntary diffusion) is a *sine qua non* condition for increasing the amount of innovative opportunities. Wider diffusion of knowledge and timely, inexpensive access to new findings reduce wasteful duplication of research efforts; putting information into the hands of a more diverse population of researchers also tends to increase the probability of useful new ideas arising from novel and unanticipated combinations. Thus knowledge spillovers is a crucial issue when one looks at the determinants of the evolution of knowledge at the sectoral level (David and Foray, 1995).

Because knowledge is difficult to control privately and private agents develop effective absorbtive capacities, competitive markets are a very potent way in which to generate involuntary spillovers, i.e a knowledge infrastructure that creates private as well as social gains. Hence, there is a “pool of knowledge” which is automatically maintained by the involuntary spillovers, which are themselves a result of competition[5]. In sectors that are not fully part of the market, such as education and health, the diffusion of knowledge is less automatic, and administrative measures or “reforms” aimed at disseminating knowledge and new practices will fail to have as much impact as competitive markets. Thus, knowledge spillovers are considerably more significant in competitive sectors of the economy.

2.3. A matrix to identify four types of knowledge base

We have thus a model describing various contexts for knowledge creation and advances in know-how.

A sector in which the “S-i-T” model works well and which is characterized by a high degree of competition, is a sector where an extremely rapid rate of innovations and a spectacular advance of human know-how may be expected. By contrast, sectors in which the science-technology interface does not work properly and the environment is less competitive is a sector where slower process of knowledge accumulation may be predicted. These two parameters can be combined to yield four cases illustrating various modes of knowledge production and accumulation. At this stage, nothing can be said about the comparative advantages of the various contexts. As already noted, a system of learning-by-doing characterized by proper mechanisms to fully exploit learning opportunities and maximize knowledge externalities can be as powerful as a model based on “science illuminating technology”.

Degree of competition Science and technology interface	Competitive environment	Non (or less)-competitive environment
Science model (Science is in a predictive stage, formal R&D is crucial and knowledge is highly codified)	Biotechnology, Semiconductor	Defence equipment
Humanistic model (Learning-by-doing is the key process, formal R&D is of a secondary importance and knowledge is poorly articulated)	Consulting activity	Education (primary school) Early XIX° medicine

table 1: A matrix to identify four types of knowledge base

[5] - See Steinmueller, 1996, who develops the case for the IT industry, Appleyard, 1996, for the semiconductor industry and Cockburn and Henderson, 1997 for the pharmaceutical industry.

In contrast to a detailed representation of a sectoral knowledge base, such a representation does not pretend to describe in exhaustive detail those institutions and practices supporting the production and the distribution of knowledge. The aim is rather to suggest the existence of some kinds of "dominant" characteristics in a knowledge base of a certain sector. The upper row describes cases in which R&D is a key pillar of the knowledge system. Deliberate, formal efforts to produce knowledge are taken seriously by entrepreneurs and decision makers, as such efforts are a considerable part of overall innovation efforts. In these situations, companies are eager to link themselves to scientific networks. The lower row describes cases in which the relation between research and the production of goods and services is of secondary importance and in which the lack of codification can impede the diffusion and re-use of knowledge. Column 1 involves areas where involuntary spillovers are important and determine the existence and growth of a “knowledge infrastructure”. In these sectors, the absorptive capacities of firms are key factors in the diffusion of knowledge. Column 2 covers the opposite case[6].

2.4 . Variations and divergencies within sectors

However, it cannot be assumed that there is consensus in a sector about the nature of its knowledge base. At any one point a sector may contain competing knowledge bases, though one of them may eventually become dominant and displace its competitor(s).

A sector may be taken to constitute a *community of practice* (Lave and Wenger, 1991; Wenger, 1998), that is, a set of practitioners who participate in an activity system about which participants share understandings concerning what they know and what they do, and what that means in their lives and for their communities. The community has a domain-specific knowledge base that both guides practice and makes sense of the community’s heritage. Medical doctors and schoolteachers may be treated as examples of communities of practice.

Within such professional communities of practice there will be sub-communities, characterised by variations and divergencies from the community of practice as a whole. Such variations reflect what Knorr Cetina (1999) calls *epistemic cultures*, which are cultures that create and warrant knowledge. All communities of practice have a positive orientation to ‘best practice’ – which may be something preserved in the community’s traditions as a standard to which practitioners aspire, or something yet to be identified within the community and disseminated to members. The methodology a community adopts to determine best practice within its domain will reflect the dominant epistemic culture within the community. An epistemic culture can, thus, be defined as a means of identifying best practice.

[6] Table 1 provides, thus, a structure of sectoral diversity in terms of how the knowledge base is built and expanded. This is a good opportunity to emphasise the cruel lack of indicators for those sectors, which are not fitting well in the “S-i-T” model (these sectors are located in the two quadrants of the lower row). Indicators of the knowledge-based economy have, on the whole, been based on existing statistics, which primarily were shaped by the dominance of the “S-i-T” model. This is very clear when we look at the most recent publication by the OECD on the subject (OECD, 1999). The light that these indicators shed on the subject is therefore more relevant for some fields than for others. In certain cases it is satisfactory – the case of science-based industries – but in others these indicators illuminate an almost empty stage, for the economics of knowledge happens elsewhere, in an area that our indicators still leave in the dark. That is typically the education sector, where R&D does not play a big role or at least where it is of secondary importance compared to experimental learning in school and the diffusion of tacit knowledge produced in these conditions (Murnane and Nelson, 1984; Hargreaves, 2000, Nelson, 2000). Thus, it is the centre of gravity of the knowledge base that differs largely from one sector to the next. And when this centre of gravity moves too far away from R&D and the diffusion of codified knowledge, our indicators do not shed light on very much at all (Foray, 2000).

A prime example of an epistemic culture is science. Different communities of practice – physicists, chemists, biologists - may nevertheless subscribe to the shared epistemic culture of science. Other professional communities of practice may be differentiated into sub-communities that subscribe to different epistemic cultures. The social sciences are notoriously divided between the two major epistemic cultures – the *Naturwissenschaften* and the *Geisteswissenschaften*. Within anthropology, for example, the physical anthropologists are orientated to the scientific epistemic culture, whereas social anthropologists are orientated to an interpretative version of social science.

3. Why is the education sector traditionally characterised by a slow development of knowledge?

Consider the efforts to develop more effective educational practices in schools. Nelson (2000) has argued that this is clearly a sector characterised by a slow process of knowledge creation about teaching. "*This is not to say that there is no understanding about principles of good teaching. But these have been known for generations. And it is not clear that we know much more now than one hundred years ago. This clearly stands in sharp contrast with other arenas of human know how, like information processing and communication, or transport*". To put it in somewhat less dramatic terms, one can at least claim that even if we do know more about educational practices that we did, the knowledge creation has indeed been very slow and there have been severe difficulties in diffusing the "superior" knowledge.

A robust explanation is that knowledge creation in this sector is not based on the "S-i-T" model and that there are very few knowledge spillovers. Or to put it with other words the humanistic culture (mainly covering learning-by-doing processes) is both persistent and very influential. Substantial evidence collected and presented in OECD (2000b) shows that the science-technology interface is problematic and innovation diffusion does not work well in the education sector. In this section, we will provide a description of the structure and dynamics of the professional knowledge-base within the education sector[7]. This evidence is analysed under three distinct headings[8]:

- Formal R&D is of secondary importance. The ability to conduct educational experiments is limited, so that many benefits of research and learning are not exploited.

- Most of the practical knowledge remains tacit, so that an important contribution of knowledge codification to the rapid accumulation of human know how is keeping at a low level.

- There is a great deal of innovation without R&D (learning-by-teaching). However, two factors limit the economic value of those innovations: i) Linkages and feedbacks between formal R&D and professional practices are weak so that the practical knowledge of the innovative practitioners is rarely drawn upon by professional researchers. ii) Due to the absence of proper incentive structures, informational

[7] - This study draws on the work of D.Hargreaves (1999, 2000, 2001) on the organisation of knowledge within the education sector. It uses also the data and evidence collected by the Center for Educational Research and Innovation (OECD) on "Innovations that work" (CERI, 1999). Although this case study has not been carried out on a national basis, most evidence is based on the analysis of the UK system.

[8] - The case study is focusing on primary school teachers where pedagogical content knowledge (how to teach, how to structure the teaching of the subject so that children learn) (Shulman, 1986) is considered as the core of the professional knowledge base while the subject knowledge (mathematics or history) is of secondary importance. And this might be reversed at the secondary school level where the knowledge base is seen to lie in the subject knowledge of the professor, that is knowledge acquired through a conventional university degree, of the subject of the school curriculum. Although teaching any kind of « science » requires very much more than immersion in the science knowledge base (Hegarty, 1999).

spillovers and diffusion of innovation are keeping at low level: much innovation in education, unless it is mandated, does not get beyond the classroom where it has been generated.

3.1. Weak role for science

Formal R&D is of secondary importance both for the training of people and for the generation of useful innovation. In the words of Murnane and Nelson (1984), R&D should not be viewed as creating 'programs that work' and only provides tidy new technologies to schools and teachers. It is, thus, certainly a mistake to think of educational R&D as like industrial or biomedical R&D (i.e. generating knowledge of " immediate " value for solving problems and developing applications)[9].

As Nelson suggests (2000), an immediate explanation deals with the limited ability to conduct educational experiments, the results of which provide reliable guides to how to improve teaching practices in real world settings: what is reported to work in a labschool or in another chosen testing locus has been hard to duplicate outside of the locus of the original research. "*Part of the problem has been that it is impossible to describe what the experimental treatment was with sufficient precision and detail so that one could know whether one was replicating it or not. Part of the problem also surely is that the context conditions that enabled a particular treatment to work were not fully known, and not necessarily in existence in other places*" (Nelson, 2000). Thus, one of the basic conditions of the model of "science illuminating technology" simply does not work here. However "limited ability" does not mean inability and techniques are currently developed in some educational R&D labs to conduct randomised controlled trials (Fitz-Gibbon, 2001) (see next section).

There will of course continue to be contributions from social science theory to education. However, they will in the short term be too few to provide the improved knowledge base that teachers now need. Much of the basic research dealing with promising areas such as neuro-sciences or cognitive psychology, is likely to be conducted in university faculties of psychology rather than education, which creates problem in the diffusion of such new knowledge into the university departments or teachers colleges that bear responsibility for initial teacher training and the continuing professional development of experienced teachers. Schools of education often have tenuous links with psychology departments. In other words, even if cognitive psychology does, over coming decades, generate a potentially powerful knowledge-base for teachers, there is no adequate system for mediating such knowledge into the teaching profession. This is not to say that there is no link at all (psychology is an established part of the teacher training curriculum). But the access of schools of education to the knowledge frontier in cognitive psychology is proving to be problematic.

Finally, the modest scale of educational research has to be noted. As emphasised by Hegarty (1999), in the UK, total expenditure on educational research is estimated at £50-60 million per year, while R&D expenditures in the pharmaceutical industry are about £2billion.

3.2. Low codification of knowledge causing weak cumulativeness

"*One of the most notable features of teacher talk is the absence of a technical vocabulary. Unlike professional encounters between doctors, lawyers, garage mechanics or astrophysicists, when teacher talk together any reasonably intelligent adult can listen in and comprehend what is being said …[and]…the uninitiated listener …is unlikely [to] encounter many words that he has never heard before or even any with a specialised meaning*" (Jackson, 1968). This absence of technical language determining the absence

[9] -Statistical studies of course provide significant results (such as the relation between the education and the income of a pupil's parents), but as correctly points out by Nelson (2000), such a correlate gives no information as to how to improve the performance of schools given the background of the students.

of professional codebooks (Cowan et al., 1999) is certainly critical in explaining the lack of codification efforts. The knowledge of the effective practitioner remains in its tacit state and this is a critical element in explaining the difficulties and impediments to knowledge creation and diffusion in education. There is no equivalent for the field of pedagogical knowledge to the recording found in surgical cases, law cases and physical models of engineering and architectural achievement. Such records, coupled with comments and critiques of highly trained professors, allow new generations to pick up where earlier ones finished. Thus "..*the beginner in teaching must start afresh, uninformed about prior solutions and alternatives approaches to recurringpractical problems. What student teachers learn about teaching, then, is intuitive and imitative rather than explicit and analytical; it is based on individual personalities rather than pedagogical principles"* (Lortie, 1975). Low codification in the education sector makes it difficult to produce "learning programs" or codified instructions that can be made the subject of comment and addition by practitioners. Teachers in regular classrooms develop their own classification systems and rules of evidence.

As it is now recognised, knowledge codification is not only a means to support information circulation and storage at very low marginal costs. Because codification requires *a priori* modelling to express knowledge in a system of "graphemes", it is also a crucial tool to create new cognitive opportunities. This function of codification – the translation of holistic aural or pictorial expressions into symbolic content, stripping away their individually expressive character – has broader cognitive implications than the "simple" improvement of information transfer and storage processes. These implications have been studied by Goody (1977) and, more recently, by Foray and Steinmueller (2001). In particular, codification shifts language from the aural to the visual domain, making it possible to arrange and examine knowledge in different ways. At a very simple level, written recipes and other kind of instructional documents can be made the subject of comment and addition. Then, experiment, assessment, the isolation of common elements, all are encouraged by written documents whose very existence changes the course and nature of the activity (here learning to teach) (Goody, 1977). As generating new cognitive opportunities, knowledge codification is a condition for rapid knowledge production and accumulation.

3.3. The economic value of learning-by-teaching is hampered by two factors

Primary education is a sector where forms of "learning-by-doing" are the main mechanism for generating knowledge.

"*Essentially teachers are artisans working primarily alone, with a variety of new and cobbled together materials, in a personally designed work environment. They gradually develop a repertoire of instructional skills and strategies, corresponding to a progressively denser, more differentiated and well-integrated set of mental schema; they come to read the instructional situation better and faster, and to respond with a greater variety of tools. They develop this repertoire through a somewhat haphazard process of trial and error, usually when one or other segment of the repertoire does not repeatedly….Teachers spontaneously go about tinkering with their classrooms*" (Huberman, 1992). An interesting parallel with doctors can be considered. Primary education and health care are sectors where forms of "tinkering" are the main 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 treatment until they find something that 'works' with the client, whether patient or pupil. In short, they learn to tinker, searching pragmatically for acceptable solutions to problems their clients present.

However, the learning potential of those processes are not well exploited at the system level:

A first problem deals with the weak feedback from the production of practical knowledge to science. There are three impediments to the creation of more teacher-researchers and the full exploitation of the potential for experimental learning. The first is simply the lack of funding. Many teachers are willing to do research, and to do so in partnership with universities, but they lack the resources to pay for the substitute or additional teachers needed to release them for classroom duties. The second and related impediment is the failure to re-shape the profession so that teacher work in classrooms is set at a higher professional level. When teachers are asked to estimate the proportion of their time in school that is devoted to tasks that can be done efficiently and effectively only by a qualified and experienced teacher, the answer is usually under 50%. By contrast, doctors learn to delegate their much of their work - the minor ailments that are easy to treat, or some specialised tasks - to trainee doctors, nurses or other para-medical staff. By delegating more to assistants, teachers could reserve to themselves the more important educational problems that require high level skills, experience and professional judgement. The exercise of the profession would thus become more rewarding and satisfying - and it would leave space for, and the incentive to pursue, research into more effective professional practice to strengthen teachers' knowledge-base. That many teachers lack the confidence to engage in research is a third impediment. There is now a significant pool of potential researchers among teachers, namely those who have undertaken a higher degree in education, which often includes research training and some practical research experience. With more support such teachers could continue with some research and quickly establish the principle of the teacher-researcher. As a consequence, the practical knowledge of the experienced practitioner is rarely drawn upon by professional researchers.

Of course there are several success stories of academic/researchers working alongside teachers. There is however, in most of the OECD countries, a fundamental weakness in the creation and development of efficient linkages between teachers and researchers.

The second problem deals with the issue of horizontal diffusion. We started this section by showing that there is massive innovative activity and potential locked up in the 'tinkering' of teachers in their classrooms, finding local solutions to pedagogic problems. The problem is that teachers have no natural incentive to diffuse their findings (and this stands clearly in contrast with, for instance, innovators in any supply industry). This is the result of these innovative activities - if only codified - that should provide the basis for strengthening a teacher's knowledge base (rather than any new development in cognitive psychology). More and better studies of " what works " in schools and classrooms could provide a knowledge base. However, much innovation in education, unless it is mandated, is not diffused, because insufficient attention is paid to the deep problems associated with adoption, implementation and institutionalisation. There are, of course, some institutional channels that support knowledge flows. Some professional associations work as "epistemic communities". Professional journals play also a role in disseminating informations about new innovative practices. However, in most countries, professional journals are more a newspaper than a scholarly journal, and thus do not play a significant role in mediating research evidence to strengthen the knowledge base of teachers.

In such a state, innovations may occur but there is very little probability of exploiting them at the system level. If any agent who innovates does not share what he knows, the implication for the whole system is that any other agent facing the same problem must invest in developing a solution anew. As the number of agents that must duplicate answers goes up, clearly the system-level efficiency goes down.

4 – Trajectories of knowledge development : a national example

In terms of our model – see Table 1 – whilst different sectors in their current state may lie clearly in one of the four cells, this ignores the historical development of the its knowledge base. It is possible that over time a particular sector has followed a complex trajectory which, in terms of our model, means that the sector should be placed in different cells as its knowledge base changes. When a community of practice changes its epistemic culture, its means of identifying best practice is also likely to change.

Degree of competition Science and technology interface	Competitive environment	Non (or less)-competitive environment
Science model (Science is in a predictive stage, formal R&D is crucial and knowledge is highly codified)	Biotechnology, Semiconductor	Defence equipment
Humanistic model (Learning-by-doing is the key process, formal R&D is of a secondary importance and knowledge is poorly articulated)	Financial services Consulting activity	Education (primary school) Early XIX° medicine

Table 2 – Examples of developmental trajectories

During the nineteenth century the medical profession changed its epistemic culture under the influence of modern science, and this led the rapid growth and accumulation of medical knowledge that continues to this day. The competition between epistemic cultures among doctors is vividly illustrated in George Eliot's novel *Middlemarch*, published in 1871 but set in the 1830s and later. In modern medicine the various sub-communities that make up the 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 community. It is arguable that some branches of psychiatry, under the influence of psycho-analysis and its subsequent development, also stand outside the epistemic community of science and fall within an epistemic community that might be called *humanistic* (as essentially covering pre-scientific learning-by-doing). It is possible for some members of a community to espouse two epistemic cultures, as when a medical practitioner subscribes to both conventional *and* alternative medicine, or a psychiatrist follower of R D Laing also uses drugs as part of the therapy for a schizophrenic patient.

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.

The developmental trajectory of medicine may thus be described as a movement from a pre-scientific and relatively non-competitive model in the nineteenth century into an S-i-T model that marked the transformation of the medical community of practice from a pre-scientific to a scientific epistemic community (see Table 2). However, elements of humanistic model persist, in that in applying science-based medical knowledge to the individual case, doctors see their practice is more artistic and humanistic terms. In 1871 the famous American physician Oliver Wendell Holmes asserted that *Medicine is the most difficult of sciences and the most laborious of arts.* A hundred years later a distinguished English physician, Lord Platt, echoed the sentiment when he described successful diagnosis as a *skill more closely allied to the skill of a connoisseur examining a picture or old violin than it is to what we normally think of as science* (Hargreaves, *et al.*, 1997).

In more recent times, the national health service in Britain was, during the Thatcher years and subsequently, pushed into a more competitive environment. Competition within public sector medicine, as well as between the public and private medical sectors, was encouraged by government in order to promote greater responsiveness to the consumer and so greater efficiency and effectiveness. In our model this policy change should be associated with an increase in knowledge creation, accumulation and diffusion.

Education is following a different developmental trajectory. Until the end of the nineteenth century, it was in a non-competitive, pre-scientific state. The application of science to educational problems was much slower than in the case of medicine. Relative to medicine, the results for education in the first half of the twentieth century were disappointing and in some quarters led to an abandonment of the scientific model for educational research. The disputes in the social sciences as a whole, over whether they could or should be essentially science-based, are inevitably reflected in the study of education in universities and. There is a powerful bifurcation between two fundamentally opposed epistemic cultures. On the one side stand those who believe that it is possible to treat medicine as a potential model for the advance 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 epistemic culture of humanism that has deeply influenced work in the arts and humanities in the universities. To this latter group, 'best practice' consists in the judgement, based on depth and breadth experience, of the individual practitioner to the unique case: and it is achieved through 'reflective practice', a widely used term taken from Schön (1983).

In Britain during the Thatcher era, there was a policy of increasing competition between schools, through greater parental choice and information provided to parents about school performance based on the results of tests and examinations and published in 'league tables'. This approach has been maintained since 1997 by the Labour government, which has been highly favourable to evidence-based policy and practice in education and other areas, in parallel to developments in medicine, with an increased commitment to educational research and its direction. This combination is driving education to the same destination as medicine in our model, but the route differs, since in this case the introduction of competition precedes the stronger scientific base to R&D (see Table 2). It is also more disputed within the educationists' community of practice: this is a divided community, not one dominated by the epistemic culture of science with a smaller alternative community that adheres to the culture of humanism. There are substantial numbers of academic educationists who are deeply hostile the epistemic culture of science 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.

In medicine the general practitioners or family doctors broadly share with the intellectual leaders in higher education, medical schools and teaching hospitals a commitment to the epistemic culture of science. In education, by contrast, teachers in schools remain largely ignorant of, and entirely indifferent to, the battles of the competing epistemic cultures that characterise the Schools of Education in universities that conduct research and control the initial training of teachers. Where practising teachers are influenced by the academic culture of Schools of Education, 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 in Britain that one of the two epistemic cultures will prevail in university-based study of education. The teaching profession's community of practice will thus not, as happened in the case of medicine, subscribe to a dominant epistemic culture, but will come to share elements of *both* epistemic cultures in a new synthesis of practice that selects and blends elements of both. We predict that there will be pressures towards such a synthesis because of the current pressures in both cultures to disseminate best practices. The methodology for determining best practice differs between the epistemic cultures of science and humanism. The scientific approach will stress the need for experiments to yield formal and explicit knowledge of 'what works', the action involved being carefully specified and disseminated through written and visual media (articles, books, videos etc). The humanistic approach will identify best practice as embodied in outstanding practitioners who will disseminate their tacit knowledge and practice through modelling, mentoring and coaching. The most discussed mode of diffusion – networking – is common to both epistemic cultures. Through the shared commitment to innovation of networking systems, the two cultures may begin to integrate as they impact upon and influence the practices of teachers in schools. Networking involves a complex admixture of collaboration and competition, as the work of Saxenian (1994) shows on the success of Silicon Valley, not on competition alone. We therefore predict that to achieve the highest form of knowledge creation, application and diffusion in education will require policies that promote this combination of competition and collaboration, not competition alone.

5 - Conclusion

The question raised in this paper is whether the "S-i-T" model (so powerful in some sectors) is a model that can be "exported" to sectors in which the ability to conduct useful experiments "off line" is limited? Probably not. On the one hand, a simple transposition of the model "S-i-T" to those sectors is not a correct option because science will never illuminates technology in the same way that it does in the cases of ICTs or some kind of medical treatment. On the other hand, evidence collected in countries that have initiated the creation of a market for schools (through the provision of information about school performance and the promotion of greater parental choice) show that increasing competition seems to be necessary but not sufficient to increase knowledge spillovers (Meuret *et al.* 2001).

Issues and problems related to knowledge development can be classified broadly into those dealing with knowledge creation and those dealing with knowledge transfer and diffusion.

Regarding knowledge creation, we believe that a relevant approach for sectors like education is to promote the two models in a consistent way: i) carrying out some kind of experimental research (based for example on randomised controlled trial) and; ii) creating the proper conditions to maximise the social benefits stemming from the development of learning-by-doing expertise. While the former option has to be targeted towards precise and well-focussed problems (for instance what kind of software should be used for this kind of pupils), the latter acknowledges the fact that each teacher can perform experiments while providing teaching services and that there is a value to exploit those experiments at the system level. Formal R&D may guide and inform the professional trial-and error learning process; and the knowledge, which is generated as by-product, must be carefully "managed".

Beyond the problem of knowledge creation (through the science and/or the humanistic model) knowledge transfer remains an important issue within both models (one should not overestimate the benefits of the science model in terms of knowledge diffusion[10]). Diffusing knowledge about teaching from one person or context to another may be more like a process of biological *grafting*. That is, one needs to know as much about the recipient as about the donor if one is to overcome the tendency of the recipient, whether an individual teacher or a school, to reject what it is intended to transplant. Put another way, knowledge transfer in this sector may require the development of a kind of *immunological knowledge*.

[10] - Substantial evidence shows that the transfer of knowledge from science to industry raises many issues and that there are many sources of inherent conflict between scientific and industrial partners (see for instance David *et al.*, 1994).

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