Creating knowledge

The power and logic of articulation

Håkanson, Lars

Submitted to *Organization Science*

Creating Knowledge
The Power and Logic of Articulation

Lars Håkanson

Department of International Economics and Management
Copenhagen Business School
Howitzvej 60
DK-2000 Frederiksberg
Denmark

Email: lh.int@cbs.dk

December 2002

CREATING KNOWLEDGE:
THE POWER AND LOGIC OF ARTICULATION

Abstract

In spite of the significance assigned to the idea of 'tacit knowledge' in recent literature, there is no consensus as to precisely what is meant by the term. Moreover, the current interest in the tacit aspects of knowledge has tended to divert attention from the economically much more obvious significance of its converse, explicit or articulated knowledge, and, by implication, the importance of articulation, the process through which tacit skills and knowledge are made explicit. This paper addresses both of these problems.

The paper analyzes the relationship between economically significant skills and capabilities and the various types of knowledge that inform them. Based on a taxonomy of knowledge, historical and present day examples are used to illustrate the significance of articulation – the process whereby tacit knowledge becomes articulated – and codification – the process of rendering articulated knowledge in fixed, standardized and easily replicable form.

The model is applied in a discussion of the incentives that induce epistemic communities to articulate their knowledge. It is argued that with two major exceptions – social skills and creativity – most forms of economically relevant knowledge can be articulated. Whether or not articulation will take place will be determined by the expected benefits, the value attached to these benefits and by the cost and effort required. The benefits include (1) the speeding up of innovation and knowledge creation, (2) advantages associated with division of labor, and (3) improved capabilities for replication and control. The costs depend on the availability of suitable codes, theories and tools.

Emphasizing the roles of different kinds of epistemic communities as the locales where knowledge resides and as agents of articulation and knowledge creation, the paper outlines a number of theoretical implications regarding the role of knowledge – tacit and otherwise – for the competitiveness of firms and in 'knowledge based' versions of the theory of the firm.

(Tacit knowledge; Articulation; Epistemic communities)

> The current, and justified, fascination with the tacit component of knowledge... must not cloud the fact that organizations to a large extent are 'articulation machines,' built around codified practices and deriving some of their competitive advantages from clever, unique articulation. In fact, much of industrialization seems to have entailed exactly the progressive articulation of craftsman-like skills, difficult but not impossible to codify." (Hedlund 1994, p. 76)

INTRODUCTION

In a whole range of areas, including strategy, organization, knowledge management, science policy and others, 'tacit knowledge' has become a fashionable brand of snake oil, invoked to explain an increasingly wide and disparate range of phenomena, both merely hypothetical ones and ones actually observed. However, in reviewing the literature the reader is struck by the extreme conceptual ambiguity, theoretical confusion and lack of agreement characteristic of the way the term is being used: As noted by Cowan *et al.* (2000), in an interesting critique of this fact:

> [M]ore than having become merely another overly vague bit of fashionable economic jargon, 'tacit knowledge' now is an increasingly 'loaded' buzzword, freighted with both methodological implications for microeconomic theory in general, and policy significance for the economics of science and technology, innovation, and economic growth. (Cowan *et al*. 2000, p. 212)

Moreover, the present interest in the tacit aspects of knowledge has tended to divert attention from the economically much more obvious significance of its converse, explicit or articulated knowledge, and, by implication, the importance of *articulation*, the process through which tacit skills and knowledge are made explicit. Heeding Gunnar Hedlund's advice in the epigraph, this paper shares with Cowan *et al.* 2000 the ambition to redress this imbalance.

Given the lack of agreement in the literature, the *first* aim of this paper is to formulate a logical and consistent set of definitions of the central concepts involved: the distinction between 'tacit' and 'explicit' knowledge and the nature of 'articulation' – the process through which the former can be transformed into the latter. The *second* aim is to model the structures and mechanisms that allow epistemic communities – through articulation – to develop new skills and create new knowledge, to discuss the conditions under which articulation is likely to occur and to outline some of its consequences. *The overall objective is to contribute towards the formulation of a coherent framework for describing and analyzing organizational knowledge structures and to outline some of its theoretical implications.*

THE NATURE OF TACIT KNOWLEDGE

In the two decades since Nelson and Winter (1982) brought Polanyi's notion of 'tacit knowledge' to the attention of economists, the concept has – as Cowan *et al*. point out – come to enjoy a "wonderful new career":

> …[A] notion that took its origins in the psychology of visual perception and human motor skills has been wonderfully transmuted, first from an efficient mode of mental storage of knowledge into a putative epistemological category… from there into a phenomenon of inarticulable inter-organizational relationships and finally to one of the keys to corporate, and perhaps also national, competitive advantage! (Cowan *et al*. 2000, p. 223)

In the process, the nuanced treatment in the original discussion (Nelson and Winter 1982, Chapter 4) has been lost and the profession has failed to even approach consensus as to the terminology and its conceptual basis.

'Tacit knowledge', it is generally agreed, is revealed through application and cannot be written down. However, regarding the possibility of transforming – articulating – tacit knowledge into explicit knowledge, there is no such convergence of views. According to Grant and Baden-Fuller (1995, p. 18), for example, 'tacit knowledge' is "by definition" not capable of articulation. In a similar vein, Reed and DeFillippi (1990, p. 89) define 'tacitness' as "the implicit and *uncodifiable* accumulation of skills that result from learning by doing." (Italics added.) Other writers define 'tacit knowledge' as knowledge that is 'difficult' to articulate, but the conditions under which this is possible and desirable remain obscure:

> Tacit knowledge is knowledge that is not codified. If it could be codified, then it would no longer be tacit knowledge; it would have become explicit knowledge. It is possible to convert some tacit knowledge into explicit knowledge… but much tacit knowledge is difficult, if not impossible, to codify and can never be made explicit. (Berman *et al*. 2002, p. 14)

Wagner and Sternberg (1985) avoid the issue altogether: "By *tacit*, we refer to knowledge that usually is not openly expressed or stated… [W]e do not mean to imply that this knowledge is inaccessible to conscious awareness, unspeakable, or unteachable, but merely that it is not taught directly…" (Wagner and Sternberg 1985, pp. 438 f.).

Taking a slightly different approach, Grant (1996a, p. 111) identifies "knowing how with tacit knowledge and knowledge about facts and theories with explicit knowledge." He does not seem to exclude the possibility of articulation: "*If* tacit knowledge cannot be codified…

its transfer between people is slow, costly and uncertain." (Italics added.) This suggests that tacit "knowing how" can be codified into explicit "knowledge about facts and theory" but the implications of such a transformation are unclear. Can knowledge be tacit and explicit at the same time or does 'knowing how' disappear in the process?

In fact, the curious idea that articulation 'destroys' knowledge is not uncommon in the literature. Soo *et al.* (2002, p. 131) provide one of its more extreme expressions: "True knowledge", they claim, is "by definition" non-codified. "As soon as it becomes codified and transmittable it ceases to be knowledge and becomes data."

Although not so specific about the precise mechanisms, Kreiner (2002) seems to have something similar in mind:

> To transform [through articulation and codification] tacit knowledge into company property is a legitimate managerial goal. It makes good sense to find ways of taking care of the knowledge that leaves the company at night. But simply put, the less knowledge that leaves in the evening, the less knowledge returns in the morning. (Kreiner 2002, p. 21)

The examples of 'tacit knowledge' given in the literature typically refer to simple motor skills, such as swimming, bicycle riding or tennis – far removed from the type of skills likely to provide competitive advantage to firms. More economically relevant examples are rare, although Subramaniam and Venkatraman (2001, p. 362), for example, present as a 'tacit insight' the fact that U.S. consumers tend to snack while using the telephone. (Discovering this intriguing "tacit habit" of soiling cordless phones is said to have offered Sony a "unique innovation opportunity".)

In spite of their various interpretations as to its precise nature, most writers concur that 'tacit knowledge' is an important source of competitive advantage. The notion is based on the belief that tacit knowledge is difficult to imitate and has become popular because of its neat fit into the prevailing 'resourced based view' of strategy. Following Winter (1987), the idea is often combined with its converse, i.e. explicit knowledge is by nature easily imitated and can therefore only provide momentary advantage. The conclusion commonly made is that it is easier to appropriate the returns to tacit than to codified knowledge.

Since 'tacitness' is typically associated with a lack of understanding, this train of thought often comes perilously close to identifying ignorance as a means to sustainable competitive advantage. Reed and DeFillippi (1990, p. 91) note, for example, that "… tacitness generates ambiguity through the skilled operator's own level of unawareness of the actions that he or she undertakes." Normatively, they suggest (p. 98), "…reinvestment in ambiguity should be aimed at competencies on which advantage is based and from which ambiguity is derived."

As noted by Hedlund and Zander (1993) almost a decade ago, the root of the problem is that 'tacitness'…

> … is defined as a negation of something in itself undefined. It is posed as that which is not articulated, articulable, codified or codifiable. As in all cases of negative definitions, the risk is that a heterogeneous assemblage of aspects is subsumed under one label. One gets the distinct feeling that authors take refuge in tacitness largely because they have encountered something they do not understand. (Hedlund and Zander 1993, p. 12)

The confusion has undoubtedly been added to also by the curious inability of the English language to easily distinguish between 'substantial knowledge' – 'know that' and 'know why' (*Wissen, savoir-connaître*) – and 'procedural knowledge' – know-how (*Können, savoir-faire*). Although the distinction is often emphasized, the nature of the simple relation between the two is generally overlooked or obscured by ill-chosen metaphors.

For Polanyi, whose main interest is a critique of positivist theory of science, the difference is not very significant: "These two aspects of knowing have similar structure and neither is ever present without the other... I shall always speak of 'knowing' therefore, to cover both practical and theoretical knowledge" (Polanyi 1966, p. 7).

However, failure to make this distinction obscures the fact that skills and substantive knowledge have different characteristics and economic implications. Substantial knowledge serves to inform the exercise of a skill: "I *can* add these numbers because I *know* (and understand) a few simple rules of arithmetic." "I *can* find my way to Piccadilly Circus because I *know* the map of London (and *understand* the codes and conventions necessary to interpret maps)." It derives its economic significance through *application* in the performance of an economically meaningful activity, i.e. the exercise of a skill.

This is not to say that all skills are reducible to a set of rules and 'knowings-that' (Ryle, 1945-1946). Polanyi's notion of 'tacit knowledge' is based on the observation that, at times, skills can be exercised without the performer being able to easily and fully account for their cognitive basis. (I *can* ride a bicycle but I cannot explain why.) This unarticulated cognitive foundation cannot be directly observed, but may, he claims, be inferred when "*...the aim of a skilful performance is achieved by the observance of a set of rules which are not known as such by the person observing them*" (Polanyi 1962, p. 49, italics in the original).

Importantly, skills vary in (1) the degree to which their exercise relies on articulable knowledge, (2) the degree to which such articulable knowledge has, in fact, been articulated, and (3) the cost, effort and means that would be required to increase the degree of articulation.

--- INSERT FIGURE 1 ABOUT HERE ---

Accepting – without going into the underlying epistemological assumptions – Plato's classical definition of 'knowledge' as 'justified true belief'[1], it appears that three types of cognitive (as opposed to procedural) knowledge can be distinguished: (1) explicit knowledge, (2) internalized knowledge (i.e. articulated knowledge of which the agent is not focally aware), and (3) tacit knowledge (Figure 1). *The three types of knowledge are complementary and – to varying degrees – most economically relevant capabilities draw on all three.*

Explicit Knowledge

Explicit knowledge is conventionally divided into 'know-what', i.e. information, knowledge of facts, etc., and 'know-why', knowledge of principles, theory, causalities and the like. It is with the aid of the latter that we interpret or 'give meaning to' the former; data without reference to cognitive schemata are meaningless.

A very large portion of the time spent in formal education programs is devoted to the teaching and (in smaller portion) learning explicit knowledge. In modern societies, professional work is unthinkable without substantial knowledge, but the same is true for many everyday activities also.

One important class of explicit knowledge is knowledge of codes and symbols. Together with knowledge of associated theory, mastery of codes is an important determinant of an agent's 'absorptive capacity' (Cohen and Levinthal 1990).

Internalized Knowledge

Over time, both in professional and everyday life, much of the explicit knowledge informing our activities become (with practice and habit) so 'natural' or 'commonplace' that they escape conscious attention. Such 'internalized knowledge' forms a second category of knowledge. (Nonaka 1991; Hedlund and Nonaka 1993; Nonaka and Takeuchi 1995; Hedlund 1994). Internalization economizes on limited cognitive, perceptual and coordinative resources, in the process transforming deliberate behavior into routines (Hedlund 1994; March & Simon 1958). Internalized knowledge informs an agent's capabilities without being in her focal awareness (Polanyi, 1962).

Internalization is often a prerequisite for proficiency (Sternberg and Horvath 1999). It sometimes takes considerable time to accomplish and may therefore have scarcity value. But in many other instances – driving an automobile, for example – the time and effort required are usually quite modest. Although the skill of pizza makers to hand toss pizza dough tends to increase with experience (Argote 1999, p. 69), the economic significance of this fact is probably limited.

Internalized knowledge shares many of the characteristics of 'tacit knowledge' and to an outside observer, the difference may be difficult to detect (Cowan *et al.*, p. 232).[2] But if prompted to do so, a person drawing on such knowledge is able – oftentimes with ease, sometimes only with difficulty – to explicate the rules underlying her performance.

Inarticulable Tacit Knowledge

The third category, 'tacit knowledge', includes, on the one hand, 'truly tacit', i.e. 'inarticulable knowledge'; and, on the other, 'articulable tacit knowledge' – knowledge that could be but has not (yet) been articulated. In the present context, this is clearly the most interesting category and it will provide the focus for most of the following discussion. First, however, a few words should be spent on 'truly tacit', i.e. inarticulable knowledge, a subject on which the inherited literature displays much confusion and widely divergent opinions.

As a rule – although this is rarely spelled out – tacit knowledge is taken to apply to acquired skills – it does not include 'natural' human faculties, such as sense perception, use of grammar and walking upright without losing balance.[3] It is striking, however, that many of the examples of 'tacit knowledge' offered by Polanyi (and the ones most often quoted) – such as the motor skills of riding a bicycle or swimming – refer to capabilities closely relying on inherited, neurologically determined faculties. Their successful performance requires speed and simultaneity of information processing. The learner must work out the detailed muscular coordination by himself, perhaps (like an apprentice) with the help and encouragement of someone mastering the art (Hedlund and Zander 1993, p. 10). These sorts of skills are 'inarticulable' in ways similar to natural faculties. Polanyi's explication of bicycle riding, for example, explains the relevant physical principles, but it is not very helpful for anyone wishing to master the art:

> The rule observed by the cyclist is this. When he starts falling to the right he turns the handlebars to the right, so that the course of the bicycle is deflected along a curve towards the right. This results in a centrifugal force pushing the cyclist to the left and offsets the centrifugal force dragging him down to the right. This manæuvre presently throws the cyclist out of balance to the left, which he counteracts by turning the handlebars to the left; and so he continues to keep himself in balance by winding along a series of appropriate curvatures. A simple analysis shows that for a given angle of unbalance the curvature of each winding is inversely proportional to the square of the speed as which the cyclist is proceeding. (Polanyi 1962, p. 49)

Polanyi's explication parallels the optical and neurological principles of eyesight articulated by the medical profession. Although in many ways useful, they are as irrelevant to the capability of seeing as knowledge of inertial forces and Newton's first law to the art of bicycling.

Sight and other natural human faculties are not accessible to consciousness and are therefore tacit. They can be theoretically explained but not articulated in ways that are instrumental to their exercise. Their analysis, although significant in areas such as neurology, linguistics and philosophy, fall outside the realm of economic enquiry.

This seems to be the line of reasoning underlying the claim by Cowan *et al.* (2000, p. 230), that inarticulable knowledge is "not very interesting for the *social* sciences." However, this statement is clearly too rash. There are at least two (and possibly more) important types of economically significant skills that are largely based on inarticulable, 'truly tacit' knowledge: *social skills* and *creativity*.

Social skills. The basis for social skills – here taken to include a wide range of capabilities such as management and leadership skills, ability to work in groups, motivate others, negotiating, selling, etc. – is typically formed during adolescence and early childhood. Later in life, experience can provide tacit knowledge regarding, for example, how to manage one-self, manage others or manage ones career (Wagner and Sternberg 1985). Such knowledge is hardly ever acquired through formal training. Educational programs, courses and seminars can only with marginal effect (if at all) hope to develop and strengthen social skills. To the extent that they do, they are typically based on methods of instruction emphasizing practical exercises and emulating the interaction between master and apprentice. Explication is typically of little avail. Etiquette can perhaps be learnt through the study of appropriate books; the skills associated with charm, charisma and a winning personality cannot be acquired in this way.

Creativity. Creativity, the ability to frame problems and to conceive of and do new things, is a further inarticulable skill (Leonard and Sensiper 1998). This applies equally to scientific discovery, the engineer's conception of a new design or the entrepreneur's identification of a new business opportunity as it does to the creation of an original work of art. Interestingly, articulation of tacit knowledge is often itself a creative activity, based at least partly on skills that are themselves inarticulable.

In science, there is a fundamental difference between the logic of discovery and the logic of demonstration. Articulation and codification constitute the very essence of the latter; discovery, at least in the true sense of finding something 'totally' new, cannot be codified. The skill of discovery – like other creative talent – cannot be prescribed and codified. This is not to preclude, of course, that – given the right circumstances – it can – as other types of tacit knowledge – be passed on from master to apprentice: "…[T]he scientist must be an accomplished craftsman; he must have undergone a lengthy apprenticeship, learning how to do things without being able to appreciate why they work" (Ravetz 1971/1996, pp. 14-15).

The argument can also be phrased differently. In all articulation, some of the perceptual texture and 'richness' of the original knowledge is inevitably lost (Boisot and Child 1988, p. 508). Sometimes, this loss has serious consequences.[4] Truly creative skills, such as those of art, music or cooking, can only be codified with extreme loss of quality. This is why the 'music' produced by electric pianos is so far from the real thing as are the hamburgers of McDonald's from a visit to Tour d'Argent.

Like all tacit knowledge, creative skills only develop slowly and with difficulty. The art of composing music has certainly developed since the 18th century, but Mozart's is as distinctive today as in his own lifetime. And it appears improbable that today's chefs are much superior to the ones preparing the banquets for the imperial court of his time. Technical progress is today more rapid than in the past, not because present day innovators are more creative than those of the past, but because they have access to a vastly expanded range of articulated knowledge.

Articulable Tacit Knowledge

At any moment in time, the boundaries between the inarticulable and the articulable are determined by the availability of appropriate codes. It is therefore difficult to differentiate precisely between skills that cannot be articulated, *as a matter of principle*, and those that cannot be so because appropriate codes are not (yet) available.

This is especially the case where – in the absence of suitable inducements – no attempts at theoretical articulation have been undertaken. Many tacit skills that are easily learnt by trial-and-error or a short period of apprenticeship do not warrant the cost of codification. That such activities remain also in very modern production plants is sometimes taken as evidence of the special (almost mystical) significance of 'tacit' skills. In reality, the fact that these skills have not yet been articulated is more often a sign of their relative lack of economic importance.

> The fact that in order to proficiently execute a standardized, well articulated productive practice workers need some experience, some assimilation of the sequence of acts they must perform etc., or that even in maneuvering a joystick some tacit personal knowledge is involved, does not seem to merit much attention from an economic viewpoint. (Balconi 1997, p. 23)

Indeed, with the exceptions noted above, it seems that most tacit skills of economic interest are at least potentially articulable. These include a large range of experience-based knowledge, informing, for example, engineering design and many manufacturing activities. Explication of such knowledge has profound economic, social and political effects. The conditions that induce articulation, the mechanisms through which it takes place and its effects are topics well worthy of study.

Articulation and Codification

In the following, 'articulation' will be taken to denote the process of expressing tacit knowledge into some socially shared code or symbolic representation – in the simplest case, ordinary natural language. However, it is useful to maintain a distinction between 'articulation' and 'codification.' While recognizing that the definitions are somewhat arbitrary and that other writers may prefer other usages, I propose to let 'codification' denote the expression of knowledge in a *standardized, fixed* form.[5]

Of course, 'standardization' and 'fixity' are not absolute criteria but relative and context dependent. The borderline between codified and non-codified explicit knowledge is sometimes fluent. Engineering designs, for example, are often first articulated in the form of 'thinking sketches' (Ferguson 1992/2001, p. 96 f.) and it may be difficult to precisely determine where on the way to the final engineering drawing 'codification' has taken place. Digital documents, such as Web pages have less fixity than those printed on paper (Brown and Duguid 2000).

Adopting this semantic convention, 'codification' presupposes 'articulation' but knowledge can be 'articulated' without being 'codified' and not all uncodified knowledge is tacit. The distinction is important both for theory and for managerial practice. It is through codification that knowledge becomes embedded in transferable artifacts that can be moved over long distances, often at minimal cost. Transmission of articulated but uncodified knowledge – like tacit knowledge – can typically be accomplished only by means of some type of personal contact.

Articulation and codification sometimes take place nearly simultaneously, but since codification may require additional time and resources this is not always the case. One of the classic problems in the implementation of 'knowledge management' systems is how to create incentives for employees to spend the time and energy necessary to codify and document their knowledge in ways that allow it to be stored and accessed (Soo *et al.* 2002, p. 141). Moreover, codifying their knowledge and making it accessible to other people entails a loss of control of it that employees may be reluctant to accept.

Therefore, articulated knowledge is sometimes never codified – or only incompletely so – and there may be considerable time lags between articulation and codification. In technology transfer, differences between 'actual' and codified knowledge can cause serious conundrum. This is often the case, for example, when blueprints have not been updated to reflect alterations to machinery made in response to experiences of actual operating conditions.

EPISTEMIC COMMUNITIES

Interpretation of articulated knowledge requires both mastery of the *code* (language, vocabulary, etc.) and an understanding of the *cognitive frames* (theories, mental maps) to which it refers. Some codes are generally learnt as part of a typical primary school curriculum, for example the conventions of writing the local language. But many require more advanced general education and yet others are learnt in specialized training programs or in actual practice.

The precise mode of articulation – both the means and symbols and the meaning attached to them – is context dependent and may vary between organizations and communities (Sanchez 1997).

> As a rule, there is no reason to presuppose that all people in the world possess the knowledge needed to interpret the codes properly. This means that what is codified for one person or group may be tacit for another and an utterly impenetrable mystery for a third. Thus *context* – temporal, spatial, cultural and social – becomes an important consideration in any discussion of codified knowledge. (Cowan *et al.* 2000, p. 225)

Defining the context delineates the community where knowledge resides. For some purposes, as in Wenger's (1998) analysis of insurance claims processors or Orr's (1996) studies of service technicians, small work groups or individual departments can be seen as forming individual '*communities of practice*'. Such communities are formed in and sustained by the common pursuit of a shared enterprise, a task to be accomplished (Lave and Wenger 1991; Brown and Duguid 1991; Wenger 1998). Interdependent practice favors the development of shared identity and this, in turn, may promote the exchange and integration of knowledge (Brown and Duguid 2001a 2001b).

Through its practice, a community develops a shared understanding of what it does, of how to do it, and how it relates to other communities and their practices – in all a 'world view'. This understanding comprises the community's collective knowledge base. The processes of developing the knowledge and the community are significantly interdependent: the practice develops the understanding, which can reciprocally change the community's practice and identity (Brown and Duguid 1998, p. 96).

As conceived in the pioneering studies of Lave and Wenger (1991), Brown and Duguid (1991, 1998) and Wenger (1998), communities of practice are formed through mutual engagement in joint enterprise and a shared repertoire of skills. Mutual engagement requires interaction and is therefore favored by geographical proximity. But, as Wenger (1998, p. 74) notes: "Given the right context, talking on the phone, exchanging electronic mail, or being connected by radio can all be part of what makes mutual engagement possible." Thus, modern transportation and communications technologies have made it feasible to build and maintain communities of practice that extend over large geographical distances. This has enabled MNCs to integrate geographically dispersed activities and combine knowledge originating in diverse locations, using the codes and shared perspectives of professionals tied by membership in common communities.

Importantly, people belong to several communities at the same time, some extending beyond organizational boundaries. Many employees, for example, identify with and maintain close relationships to professional communities that extend beyond their own organizations. This is common in many knowledge-based industries where 'normative isomorphism' through selection, socialization and training in the educational system, leads to a professional …

> … pool of almost interchangeable individuals who occupy similar positions across a range of organizations and possess a similarity of orientation and disposition that may override variations in tradition and control that might otherwise shape organizational behavior. (DiMaggio and Powell 1983, p. 152.)

Professional communities that span organizational boundaries create and legitimize common codes and cognitive frames. Due to such commonalities and the development of communication technologies, knowledge sometimes travels more easily between organizations than within them:

> ...[While] the division of labor erects boundaries within firms, it also produces extended communities that lie across the external boundaries of firms. Moving knowledge among groups with similar practices and overlapping memberships can thus sometimes be relatively easy compared to the difficulty of moving it among heterogeneous groups within the firm. (Brown and Duguid 1998, p. 102).

Sometimes such communities of practitioners are geographically concentrated, as in the case of the engineers developing the flat panel display industry (Murtha *et al.* 2001) or the communities clustering in Silicon Valley (Saxenian 1996). In the past, national borders often delimited such larger communities and their practices, but even before the advent of jet air travel and electronic communication geographical boundaries were not always important.

Scientists, for example, have long formed loose but geographically extensive communities (Knorr-Cetina 1999). Common pursuit of a shared scientific practice allows their members to communicate and collaborate over large distances, without necessarily having close personal contact.

The semantic conventions in the inherited literature are somewhat ambiguous and it is useful, as Brown and Duguid (2001b) suggest, to more clearly distinguish than is usually done such larger communities from the smaller work groups for which the term 'community of practice' was originally applied. Following recent practice (Steinmueller 2000; Cowan *et al*. 2000; Edwards 2001; Cohendet *et al.* 2001), I propose use 'epistemic community' as a generic term for such communities, regardless of the geographical concentration and intensity of mutual contact between their members.[6]

Epistemic Communities as Interpretation Systems

Epistemic communities form 'interpretation systems' (Daft and Weick 1984). They exist in order to help their members interpret the world and provide meaning to their activities. Their 'practice' is always (negotiated) social practice and includes both explicit and tacit components (Wenger 1998). *Epistemic communities are where knowledge resides and articulation and knowledge creation can take place*.

Epistemic communities are defined and delineated by the generation and maintenance of shared *cognitive frames* (theories, mental maps) and *coding schemes* (vocabulary, codes) that help the community and its members define and solve problems and 'get the job done.' Communities are also characterized by their inherited technology, much of which is typically embedded in *physical artifacts* of various kinds. It is in the interplay and interaction between these elements that articulation and codification of knowledge is possible (Figure 2).

--- INSERT FIGURE 2 ABOUT HERE ---

THE ARTICULATION CIRCLE

With the exceptions noted above, 'tacitness' is not an intrinsic property of human knowledge but is determined by the extent to which investments in its articulation have been undertaken. As illustrated in the debate over the relationship between science and technology, the impetus sometimes comes from the emergence of new tools, sometimes through the development of new and more powerful codes and sometimes through the 'independent' development of theory (Figure 3).

--- INSERT FIGURE 3 ABOUT HERE ---

A striking illustration is offered by McGee (1999), in his discussion of the impact of measured multiview plans (the 'code') on shipbuilding through the development of a coherent body of knowledge (the 'theory') regarding the relationship between various aspects of a ship's physical characteristics (the 'tool'), hull shape, displacement, weight, etc., and its behavior at sea:

> The most important [point]: drawings first, then science. Without the use of measured plans there could be nothing to quantify and so no possible application of mathematical physical theory whatsoever. The second point is that without the use of measured plans to achieve accuracy in construction there could be no point in applying scientific theory, since there could be no point in calculating the behavior of a "paper" ship if the real ship was going to be built (and therefore behave) differently – especially not when small variations in shape are known to produce large changes in behavior. The third point is that what cannot get into the plans cannot get into the ship. This is important because it gives us definite criteria for judging the utility of physical theory. (McGee 1999, p.230)

Before theories can be developed and applied to a specific problem, the problem itself must be defined. As Schön (1983/1996, p. 40) emphasizes, "problem setting… is not itself a technical problem." Frequently, both the ends to be achieved and the possible means to be used need to be clarified. Framing the problem is the first step in a process of articulation: "Problem setting is process in which, interactively, we *name* the thing to which we will attend and *frame* the context in which we will attend to them" (Schön 1983/1996, p. 40, italics in the original).

Articulation depends on existing theoretical frames also because coded messages derive meaning only in relationship to previously acquired knowledge. As theory, myth, or mental models, this knowledge provides the frame-of-reference needed to transform data into meaningful messages. Articulation cannot be undertaken without reference to theory and mental models: “Codes, and especially languages, are not neutral means to transmit knowledge. They include intrinsically a representation of the world and mobilize different amounts of cognitive resources, both for the emitter and for the receiver” (Ancori, et *al.* 2000, p. 268).

Frequently, articulation and theory development require observations and measurements that can only be obtained by artificially extending the natural perception of the senses. Thus, man-made artifacts, ‘tools’ or ‘instrumentalities’ (De Solla Price 1984), are often essential to articulation. Other tools serve as reservoirs of codified knowledge, e.g. books and libraries, blueprints and data banks. They allow knowledge to be stored, retrieved and transmitted between locations, thereby facilitating the accumulation and combination of knowledge.

Theory

In order to be useful, articulation requires not only the availability of a suitable code. It must also be accompanied by a cognitive theory or ‘frame of reference’ providing meaning to the information it conveys. The frame of reference to which a code appeals may itself be more or less articulated. The frame can be highly articulated as in the case of a scientific theory. However, such frames can also be tacit, such as the ones provided by the habits, conventions and traditions of national or organizational cultures, ‘dominant logics’ (Prahalad and Bettis, 1986) or ‘industry recipes’ (Spender, 1989).

Epistemic communities share both implicit mental models and explicit cognitive schemata that can be more or less elaborate, ranging from simple rules of thumb to explicit theories. Lave and Wenger (1991), who emphasize the tacit aspects, analyze how new members acquire the skill of the community through situated learning in a process they described – in explicit analogy to the master-apprentice relationship – as ‘legitimate peripheral learning’. Schön (1983/1996, p. 118) uses a similar analogy: “Like the individual craftsman, the collective has a theory-in-use implicit in the norms, strategies and assumptions that govern its regular patterns of task performance.”

Tacit mental models arise from the community's experience of solving the problems it encounters. As long as they help solving these problems reliably, they tend to be taken for granted and there is little inducement to invest in their articulation. However, since they are based on the range of experiences already accounted, their area of application is typically limited. When a group or an individual encounters new circumstances or attempts to reach new levels of performance, the inadequacy of inherited models may become evident.

Medieval cathedral builders lacked a theory of structural mechanics but were able to construct extremely complex innovative structures by means of simple rules of thumb that…

> … related sizes to spaces and heights by ratios, such as half the number of feet in a span expressed in inches plus one inch will give the depth of a hardwood joist. These rules of thumb were stated as, and learned as, ratios; for, as the span gets larger, the depth of the joist will too. This sort of geometry is extremely powerful. It enables the transportation and transmission of structural experience, it makes possible the successful replication of a specific arrangement in different places and different circumstances, it reduces a wide variety or problems to a comparatively compact series of solutions, and it allows for a flexible rather than rigidly rule-bound response to differing problems. (Turnbull, 1993, p. 323.)

In time, the application of these and similar rules of thumb proved inadequate to the ambition of architects and patrons. Like in many traditional engineering industries, a technological trajectory based on rules of thumb and trial-and-error methods of experimentation soon reached a point where desired performance improvements became progressively more difficult and eventually prohibitively costly.

In this situation, communities of engineers may decide to undertake research in order to develop a more adequate theoretical understanding of the materials and forces involved. Individual practitioners may similarly engage in 'reflection-in-action' (Schön 1983/1996) in order to reach a better understanding of the conditions influencing the task at hand. In both types of situations, the aim is to improve performance by means of knowledge articulation and the development of new and more powerful theory.

As long as established practice continues to provide successful innovations, there is little incentive to engage in theoretical articulation with uncertain pay-off. Over time, however, problems may appear that cannot be solved with established routines. Competitive advantages may then accrue to those firms that have the vision and competence to articulate product and process technologies through application of scientific method (Senker, 1995, p. 430).

Codes

Through 'articulation' tacit knowledge is transformed into explicit code or language, including "...writing, mathematics, graphs and maps, diagrams and pictures, in short, all forms of symbolic representation which are used as language." (Polanyi 1962, p. 78.) The inclusion of 'maps' and 'pictures' is significant – many types of knowledge cannot easily be conveyed within the serial logic of mathematics and language. As Hedlund and Zander (1993, p. 10) note, "… the relationship between the details of a complex skill, even if articulable one by one, is sometimes lost in language, which – due to its serial nature – cannot simultaneously describe the relationships and characterize the things related."

Language – both ordinary language and more specialized varieties, such as mathematics, chemical formulae or computer code – and *pictorial representations* ("graphs and maps, diagrams and pictures…") constitute basic forms of code with origins as ancient as humankind. As elaborated below, it is useful, although linguistically awkward, to regard *physical artifacts*, such as tools and machines, also as forms of articulated knowledge.

The aims of their practice and the goals of communities have a strong influence on the codes they develop and employ. An interesting example is offered by the failed attempt to provide American shipyards with ready-made (British) plans for the construction of the Liberty freighter during World War II (Brown 2000). In the second half of the nineteenth century, the engineering cultures of the two countries had begun to diverge. For a variety of reasons, including both the nature of demand and the cost and qualifications of available labor, British manufacturing firms emphasized variety and design creativity ('innovation'), American engineers were more concerned with standardization and production control ('replication'). In consequence, by 1940 the mechanical drawings used in Britain were so different from those employed in the United States as to be literally meaningless in American shipyards.

Over time, increasingly specialized and sophisticated varieties of textual and pictorial code have radically reduced the costs of articulation, permitting articulation of skills previously immune to explication. Innovations as regards the methods for producing, reproducing and storing text and images have revolutionized the impact of knowledge codification.

Language. Most economically significant codes are explicit, but some may also have tacit elements. The latter include 'patterns' of different kinds that carry meaning although we may not be able to account for precisely how this happens. In this category belong – as Polanyi (1962) notes – basic human capabilities such as face recognition, an ability acquired so early on in life that it takes on an automatic quality. But pattern recognition is also an important part of the skills of a professional:

> Every competent practitioner can recognize phenomena - families of symptoms associated with a particular disease, peculiarities of a certain kind of building site, irregularities of materials or structures – for which he cannot give a reasonably accurate or complete description. (Schön 1983/1996, p. 49)

As long as the tacit interpretation of such patterns produces the expected and desired outcomes, there is usually little inducement to articulate the knowledge on which they are based. However, at times, unfamiliar patterns may occur that cannot readily be interpreted. This may cause the practitioner to engage in 'reflection-in-action' (Schön 1983/1996), an attempt to articulate a better understanding of the conditions influencing the task at hand. Provided that a suitable vocabulary or code can be found, this may involve the articulation of a new theory or model of the phenomenon.

The nature of that transformation is intimately dependent on the availability of codes. Our ability to name things determines not only the ease or difficulty of communicating what we see. It vitally affects our very perception, i.e. our ability to see things in the first place. Language and other codes, that we use in communication and that shape our perceptions, are not stable. They develop over time, allowing progressively finer distinctions in the overall stream of experience (Tsoukas and Vladimirou 2001).

.

Pictorial codes. In the early 15th century, the Renaissance inventions of chiaroscuro (the illusion of the third dimension through shading) and linear perspective provided standard conventions for the pictorial representation of three-dimensional objects (Ivins 1938/1973; Edgerton 1976, 1980; Ferguson 1992/2001).[7] As Edgerton (1980, p. 182) notes, these conventions provided a new and powerful code: "The mathematical aspect of Renaissance art also allowed it to be used as a special visual language, particularly when describing tangible objects."

> Alberti's perspective scheme of 1435 – 1436… provided a basis for the hitherto missing grammar or rules for securing both logical relations within the system of symbols employed and a reciprocal, or two-way, metrical correspondence between the pictorial representations of objects and the shapes of those objects located in space.

These developments – and subsequent graphic inventions such as Cartesian coordinate geometry, orthographic projections and other types of engineering drawings – produced a radical change in the ease with which visual information could be conveyed.

Based on the invention of printing from woodcuts and engraved metal plates by the mid 15th century – together with Gutenberg's invention of movable type around the same time – these new codes were crucial for both the Scientific Revolution of the 17th century and the Industrial Revolution of the 18th (Ivins 1938/1973; Ferguson 1992/2001). It now became possible to exactly duplicate in large numbers both text and visual information, such as drawings and diagrams. The creation and use of pictorial symbols and associated conventions revolutionized the codification and transmission of both scientific and technological knowledge.

Codes and epistemic communities. In theory, codified knowledge can be communicated as 'information.' It is "...alienable from the person who wrote the code" and "...can be transmitted without loss of integrity once the syntactical rules required for deciphering it are known" (Kogut and Zander 1992, p. 386 f.).

However, the existence of an explicit and well-defined code does not by itself guarantee the efficient transfer of information. It also requires that the recipient is familiar with it and can decipher the message. If not, he/she must invest in learning the code of the message, or the message needs to be translated into a different code. Both solutions require conscious and costly effort and will only be undertaken if the perceived gain is high enough.

Moreover, communities-of-practice tend to develop idiosyncratic coding schemes, reflecting their common, partly tacit, interpretation of the world and their own roles within it. As noted already in Allen's (1977) classic study, idiosyncratic coding schemes often enhance the efficiency of communication among community members but impede, sometimes intentionally, communication with 'outsiders'. Like other aspects of organizational culture, local codes tend to be taken for granted and their mastery is largely tacit. Idiosyncratic codes frequently aggravates the problem of communication across organizational boundaries:

Tools

The term 'tool' is here used in its broadest meaning to denote all the various types of man-made artifacts that communities use or produce in the course of their practice. Tools are significance for the articulation process in both immediate and indirect ways. Following Rogers (1983, p. 2), three classes of tools can be distinguished, differing in the way they allow man to transform the physical world:

Many tools increase the *efficiency of the body*. This includes a wide variety of tools, ranging from simple hand tools to numerically controlled machine tools and robots, but also transportation equipment and housing, for example. Like all man made objects, they are significant here because they *embody knowledge* – both tacit and otherwise – that went into their making.

A second class of tools serves to increase the *efficiency of the senses* via instruments that permit measurements of not directly perceivable phenomena or with greater precision and reliability than possible by mere sense perception. Such *instrumentalities* (de Solla Price 1984) serve the articulation process by providing data necessary for the formulation, testing and refinement of theoretical models.

Finally, there are tools that increase the *power of the human intellect* as aids to memory, intelligence and communication. Such *memory tools* are of special significance in the present context since they serve as media for the codification, storage and transmission of articulated knowledge.

Embodied knowledge. All human artifacts, from the simplest hand tools to advanced rocketry, embody the knowledge – both tacit and explicit – that was employed in their making. "The artifact often is an exemplar of that knowledge, and can sometimes be thought of as a 'container' or 'storage vessel' for it…" (Cowan et al. 2000, p. 229 f.).

The transfer of embodied technologies increases the skill of the recipient but does not necessarily imply the transfer of the underlying cognitive elements. In the simplest case, the use of the artifact is self-explanatory, requiring no or only limited prior knowledge on part of the receiver. Argote (1999, p. 69 f.), for example, relates the rapid diffusion within a chain of pizza stores of a 'cheese spreader' – a tool to help ensure the even distribution of grated cheese on pizzas. Effective use of a 'cheese spreader' – like that of a personal computer – requires no understanding of the embodied technological principles.

In many instances, such understanding may be irrelevant for the user whose primary interest is the application of the artifact and who may be totally ignorant of manufacturing principles employed in its production. Being incidental to their primary purpose, the knowledge embodied in artifacts often has strong tacit elements. Nevertheless, an observer belonging to the relevant community of practice and versed in the appropriate production technologies may through observation and reverse engineering be able to 'decode' the artifact and lay bare the knowledge used in its design and production.

Instrumentalities. Articulation and theory development frequently require access to quantitative measurements of phenomena not readily available to natural perception or requiring a level of precision that cannot be obtained without the aid of dedicated instruments. Both for the development and testing of new theory, such measuring tools, 'instrumentalities', are often required. Vincenti's account of the articulation of 'flying qualities' offers a good illustration:

> The capability at Langley depended crucially on new instrumentation. Warner and Norton's first instruments were primitive: standard altimeter, tachometer, and air-speed meter, plus a graduated sector attached to the rocker arm of the control stick for elevator angle and a ring grip on the control column for stick force. The pilot or observer hurriedly recorded the readings on a kneepad. (Vincenti 1990, p. 70)

The causal relationship between instrumentalities and the articulation of theory is not unidirectional. Modeling the double helix structure of DNA critically depended on Rosalind Franklin's techniques to produce X-ray diffraction pictures (Watson 1968). However, it was almost a century after the publication of the *Principia* that Atwood invented an apparatus to empirically demonstrate the workings of Newton's second law (Kuhn 1977, p. 189).

Memory Tools. Artifacts are significant, first of all, because of their material properties – they can be stored and transported and are therefore able to bridge both time and space. Many – such as archives and data banks – are obviously created precisely for these reasons. However, the same is true for all objects used and produced in the process of knowledge codification: printed paper, blueprints, computer hardware, etc.

The templates used in the building of 13th century Gothic cathedrals offer an early example. Without the benefit of precise measurements, scale plans or theory of structural mechanics, portable templates, embodying geometrical rules of thumb, provided the powerful means by which complex knowledge was replicated and transmitted, facilitating accurate mass production and the coordination of a large number of workers:

> The template helps to make possible the unified organization of large numbers of men with varied training and skill over considerable periods of time…. In addition to the power to organize large numbers of workers, templates have the power to allow for greater exactness of stone cutting and enabled a stable, enduring, and coherent structure, despite a discontinuous process and radical design changes…. The template… provides a structure whose stability is achieved despite the lack of what we would take to be the basic essentials for producing the specifications for a particular element in a building, a common and precise mode of measurement, a knowledge of structural mechanics, and a detailed scale plan. (Turnbull 1993, pp. 322 f.)

Numerically controlled machine tools offer a modern day example. Complex metal cutting, for example, is slow and difficult when performed manually but can be coded with relative ease and ensured precision. And, once coded, the commands can be stored and the task need not be analyzed again.

The principle operates not only in the articulation of technical knowledge. It applies equally in the operational record keeping through which organizations create 'memories' independent of individuals. Quoting Chandler (1977), Bowker and Star (1999, p. 255 f.) discuss how organizations use classification schemes "to selectively forget about the past in the process of producing knowledge".

Tools as boundary objects. Since they are not tied in space and time, some artifacts serve as *boundary objects*, (Star and Griesemer 1989), i.e. "…objects that both inhabit several communities of practice and satisfy the informational requirements of each of them. In working practice, they are objects that are able both to across borders and maintain some sort of constant identity" (Bowker and Star 1999, p. 16). They are significant because few articulation projects take place solely within the confines of one community; most involve interaction and exchange of knowledge between communities. They are significant also because they facilitate coordinated action without requiring members of different communities to align their understanding of each other's knowledge.

Modern computer and information systems are pervasive examples of boundary objects. Their effects are important not only because they facilitate integration and new combinations of knowledge, but also because they create inducements to articulate knowledge in standardized code:

> If new knowledge is explicit, or if tacit knowledge can be articulated in explicit form, then integrating knowledge does not pose major difficulties. In designing its 777 passenger plane, Boeing was able to greatly extend its knowledge of electronics and new materials through an advanced CAD system which provided a common language for specialists across widely different knowledge areas and different companies to communicate and integrate. (Grant 1996b, p. 382)

THE BENEFITS OF ARTICULATION

Articulation and Knowledge Creation

Articulation – the conversion of tacit into explicit knowledge – is fundamental to knowledge creation and innovation. Indeed, it is a prerequisite for rapid and cumulative learning. Of course, learning can also take place without suitable codes and vocabularies – as when baseball pitchers learn to 'find the groove' (Schön 1983/1996, p. 54). However, such learning is slow, cumbersome and difficult to pass on to others. In consequence, the state-of-the-art of the community of baseball players advances only slowly over time. Joe DiMaggio, would still command a handsome reward in the World Series. In contrast, the alpine skiers of bygone days would only with difficulty qualify for a spot in the World Cup. Here, learning has been rapid and cumulative because it has been articulated and embedded in new materials and shapes of skiing equipment. As Adler and Cole (1993) illustrate, the same principle operates in industrial production plants.

Ever since the Scientific Revolution of the 17th century, we have seen a continuous trend away from the experiential and tacit rules of craftsmen towards articulated substantive and operative theories of technology (Bunge 1966). Modern technology is unthinkable without codification.

The trend towards increasing articulation is perhaps most obvious and pervasive in science and engineering, but, as noted above, it has also been a force in the development of modern management techniques, at least since the mid 19th century. Before this time, business firms tended to keep few records other than accounts and business correspondence (Chandler 1977; Yates 1989). The lack of codification paralleled that in production, the knowledge of which was largely tacit:

> In the early nineteenth century, organizational memory in American firms consisted of the memories of individuals, simple routines, and very limited records. Most firms were managed by their owners, who carried much of the knowledge of business

> methods and past successes and failures in their heads. These owner/managers/ were often aided by skilled artisans, who in turn carried most of the knowledge of technical methods in their heads and hands. Both owners and skilled employees applied their knowledge through simple standard procedures and through oral orders. This knowledge could be passed on only by prolonged apprenticeship, either technical or managerial. (Yates 1990, p. 173)

By the early 1900s, the traditional reliance (and dependence) of firms on the skills and memories of individuals (both owner/managers and employees) was increasingly replaced by written records, reports and manuals, codifying organizational rules and procedures. The introduction of 'systematic management' reflected an attempt "…to transcend dependence upon the skills, memory, or capacity of any single individual" but also "an attempt to rise above the concrete details of the task *to think about what is being done, rather than merely to do it*" (Jelinek 1980, p. 64, italics added).

This is not meant to suggest that in the modern world there are no traditional industries characterized by highly tacit technologies, nor that modern, 'science-based' industries are totally independent of such knowledge. Many of the skills of managers and much of the creativity underlying new innovations are, by their very nature, unarticulable. However, the argument does mean to imply that, if at all, such tacit elements develop only very slowly over time. Articulation is the primary force in knowledge creation and the formation of new capabilities.

The Costs and Benefits of Articulation

Articulation and codification of tacit knowledge have several fundamental benefits, which together help to account for the technical, scientific and economic progress of human civilization since the invention of writing by the Sumerians around 3000 BC. Historically, the combined and cumulative effects of new codes, new theory and new tools have made possible the articulation of ever-larger areas of knowledge. Lately, advances in the fields of electronics, computer science and scientific instruments have dramatically increased the range skills and knowledge amenable to articulation while simultaneously drastically reducing the associated costs. Of course, their impact on the production, replication, dissemination and storage of codified knowledge has been no less dramatic.

Once they are available, new codes often make possible the development of new models and new theory. New models, in turn, may lead to the refinement of existing codes or the creation of new ones. However, articulation always requires effort, especially when both codes and methods of measurements must first be invented and developed.

The decision as to whether or not to engage in articulation and incur the associated investments will be determined by the expected benefits, the value attached to these benefits and by the cost and effort required. (Sanchez 1997; Cowan *et al. 2*000). The effort will only be undertaken and the costs will only be incurred if they are expected to generate benefits in excess of these costs.

This is not to say that the process can be described as "an exercise in equilibrating marginal benefits and costs" (Johnson, *et al*., p. 257), nor can we assume that an equilibrium exist where no further benefits from articulation can be expected. In an evolutionary context, it is not difficult to imagine that fully rational economic agents may have an incentive to continuously increase the degree of codification of their knowledge. Indeed, outside the realm of neo-classical economic models, this would appear to be the rule rather than the exception.

Moreover, articulation and the development of new codes are not always and exclusively responses to rational economic calculation. The development of linear perspective and the geometrical quantitative qualities of Renaissance art have been traced to the thirteenth century cult of St. Francis which inspired painters to revive ancient Greek and Roman traditions in an effort to render the holy myths as realistically as possible (Edgerton 1980, p. 184 ff.).

Thus, decisions as to whether or not to engage in codification reflect not only economic incentives but also inherited, culturally based value- and belief-systems. In Europe, Protestant printers and Protestant ideology were instrumental in opening the way for the Scientific Revolution and in overcoming the alliance between the theology of the Catholic Church and the teachings of Aristotle (Eisenstein 1983). In China – in spite of the potential of Mohist logic and Taoist natural insight – Confucian dominance prevented a similar unfolding of scientific thinking (Needham 1978).

Beliefs, attitudes and habits also affect the articulation activities of modern-day organizations. Some tend to attach more value to articulation than do others (Wright 1997). R&D units, for example, differ strongly in this respect. Some are strongly 'normatively-oriented' (Hofstede *et al.* 1990; Håkanson 1995), aiming for a scientific/theoretical understanding of production processes. They tend to have tight control systems, reflected in stringent standards for quality control and documentation. Others are much more 'pragmatic' and consider such understanding superfluous as long as the processes deliver the right quality of product in appropriate quantities. They tend to view articulation activities and codification systems as bureaucratic and wastefully time consuming

Hence, the conditions and inducements for undertaking the investment necessary for articulation have differed over time and differ between contexts. Although interrelated, three broad categories of benefits can be identified: *innovation, division of labor,* and *replication and control*.

Innovation. One of the most powerful effects of articulation is to enhance the possibilities for experimentation and innovation. In the absence of codification, there is no symbolic means to predict whether a new design will work. The only way to find out is to build and subject it to actual conditions of use. Should the design fail, the time, work and materials involved may have been wasted. In consequence, craft production is inherently conservative, characterized by a very slow rate of innovation and change (McGee 1999).

As already noted, articulation can never fully retain the richness of completeness of the original skill. However, precisely because it conveys only a part of the original knowledge – articulation helps focus attention on its critical aspects. This accounts for the power of drawings as a method of design: "Articulation pictures *the essentials of a situation* on a reduced scale, which lends itself more easily to imaginative manipulation than the ungainly original; it thereby makes possible the science of engineering." (Polanyi 1962, p. 85, italics added)

The emergence of modern methods of engineering – "the shift from craftsmanship to draftsmanship" – was made possible by the Renaissance development of linear perspective and the use of drawings as a method of design (Ferguson 1992/2001; McGee, 1999). Already in the early 15th century, Taccola and his contemporaries were exploiting the new conventions of pictorial representation, such as the 'exploded view' and the "transparent view" to design machines solely by means of drawings, without having to find a patron to finance expensive constructions (Edgerton 1980, p. 195).

The method of 'design-by-drawing', was later extended to the use of measured drawings, specifying the dimensions of products before their actual production. This accelerated the rate of innovation by allowing designers/inventors to experiment with the geometrical aspects of a proposed design without the costs and effort of altering the product itself. The mastery of drawings as a means of experimentation and of mathematics as the language of technology is a distinguishing feature of the modern engineer (Petroski 1996, pp. 89 f.).

Articulation also increases the level of complexity that can be managed. Codification makes it possible to 'chunk', store and communicate technological knowledge. This too is exemplified in the use of drawings which enabled engineers and designers to deal with a hitherto "unmanageable, and unimaginable, degree of complexity" (McGee 1999, p. 28), unmatched until the advent of Computer Aided Design.

Division of labor. A further primary benefit of articulation is to facilitate the division of labor. Traditional craft production is undifferentiated and continuous with little or no division of labor. Artifacts are created without explicit design, using techniques that are largely tacit. The passing on of these techniques is time consuming and therefore costly. Time spent in instruction detracts from time in production. This limits the number of apprentices that a master can supervise at any one time and, thereby, his opportunity to exploit advantages of specialization and division of labor. In pre-industrial Europe, these limits were reinforced by the institutional setting of the time, e.g. in the rules of guilds and the moral sanctions of the church.

The introduction of drawings as a method of design had consequences also for the division of labor. It allowed a separation between design and production; these activities could now be undertaken at different times, by different people and at different geographical locations. Moreover, the use of measured drawings made it possible to devise, plan and execute projects – such as large ships or buildings – that were too big for a single craftsman to make.

Equally important, by enhancing division of labor and specialization, articulation can lead to dramatic improvements in productivity. The advantage of time-and-motion studies in the scientific management tradition of Fredrick W. Taylor was not only the increased productivity of the individual worker. At least as important was the transformation of work itself, from skilled or semi-skilled craft production to unskilled manufacturing jobs.

For firms, the combination of deskilling and increasing division of labor created benefits both through substantial savings in labor cost and through reduced dependence on skilled artisans. In the short run, of course, these changes negatively affected both organized labor and individual workmen (Braverman 1974). However, in a longer perspective, articulation and codification provided the basis for automation, rationalization and other technologies permitting increases in labor productivity and wages far outweighing the workers' momentary loss of power and income.

Replication and control. A common incentive for articulation and codification is to reduce the cost of capability replication. This applies, for example, to the acquisition of firm specific skills by new employees. Time spent in acquiring tacit organizational knowledge is unproductive and costly. Any reduction of this time period can clearly bring considerable savings.

Another common case of capability replication is technology transfer to licensees, joint venture partners or wholly owned subsidiaries. Empirical research has shown that the costs for such transfers are often considerable, depending on factors such as the sender's experience with prior transfers and with the technology, the skills and experience of the receiver and the characteristics of the technology itself, notably its degree of codification. (Teece 1977; Contractor 1981; Kogut and Zander 1993; Zander and Kogut 1995).

A related reason for articulation is to improve 'control', i.e. the precision and reliability with which a particular organizational routine can be performed. The quest for increasing control is the dominating theme in the seminal works of Beniger (1986) on the historical development of information technologies and Yates (1989) on the 'systematic management' movement. Although not framed in these terms, both can be read as pioneering studies in the power and logic of articulation.

Following Chandler (1977), Yates (1989) describes, for example, how, in the mid 19th century, the need to reliably manage, coordinate and control geographically dispersed operations led American railroads to pioneer major innovations in cost accounting, planning procedures and operational reporting. Explication and codification of organizational procedures remain central to controlled replication and 'quality management' – they are important elements, for example, in ISO 900x certification.

Articulation and Politics

As in the case of technical progress generally, articulation may bring benefits to some and costs to others. Braverman (1974, p.18) recalls Marx' famous statement:

> Social relations are closely bound up with productive forces. In acquiring new productive forces men change their mode of production; and in changing their mode of production, in changing the way of earning their living, they change all their social relations. The hand-mill gives you society with the feudal lord; the steam mill, society with the industrial capitalist. (Marx, n. d., p. 92 in Braverman 1974, p. 18)

The Marxist tradition emphasizes the alienation and exploitation of the working class as the primary effects of articulation and technical change: "The more science is incorporated into the labor process, the less the worker understands of the process; the more sophisticated an intellectual product the machine becomes, the less control and comprehension of the machine the worker has" (Braverman 1974, p. 73).

By the mid 19th century, the introduction of engineering drawings following standardized conventions radically changed the balance of power between managers and workers. They reduced the discretion of foremen in the shops by transferring decisions to the drafting rooms, from where complete specifications were issued according to which work was to be done:

> The transformation that occurred in most European and American shops in the nineteenth century was from a world in which engineers negotiated with workers who had traditionally used the judgment of their trades to a world in which matters of judgment were settled by pencils on paper in drafting rooms remote from the shop floor. The removal of all discretionary power was neither sudden nor uncontested, but within a few decades the center of authority in engineering work was clearly located in engineering drawings. (Ferguson 1992/2001, p. 102)

Articulation, like innovation and technological progress, almost always entails a redistribution of knowledge and skills. It has repercussions both on the equilibrium conditions in the economy and on the power balance of the social systems it affects. The articulation of the traditional, and largely tacit knowledge concerning the delivery of babies has brought a power shift from (predominantly female) midwives to (predominantly male) physicians – legitimated by the associated reduction in infant mortality rates. Articulation is not only an economic process with economic consequences; it is often a more or less intensely political process with substantial social consequences. Indeed, it is worthy of study not only because of its economic effects but also because of its social and political consequences.

THEORETICAL IMPLICATIONS

According to Winter (1987), in deciding whether or not to invest in the articulation and codification of knowledge, firms face a fundamental dilemma. Whereas the advantages of reducing the costs of voluntary replication and transfer of capabilities encourage articulation and codification, such articulation increases the risk of involuntary transfer, imitation. The idea that voluntary replication and involuntary imitation are catoptric problems has found wide acceptance and has been influential both in shaping recent theoretical attempts to construct a knowledge based theory of the firm and in the development of the resource based view of strategy.

The argument outlined above suggests a number of significant caveats to this line of reasoning. These pertain to the role of tacitness for replication, both voluntary and involuntary, and for the nature of the tradeoff between the advantages and disadvantages of articulation. Recognition of the roles of different kinds of epistemic communities as the locales where knowledge resides and as agents of articulation and knowledge creation has implications also for the role of knowledge in 'resource based' versions of the theory of the firm.

The Role of Tacit Knowledge for Competitive Advantage

Tacitness and replication. Theoretical arguments and empirical evidence lend good support to the proposition that – all things equal – the cost and difficulty of capability replication decrease with its degree of articulation and codification of the underlying knowledge. Technology transfers that can be effected through the mere transmission of an artifact or a set of blueprints are clearly much less expensive than ones requiring the personal engagement of experts in design modifications or on-the-job training. Hence, the attractiveness of investing in articulation increases with the frequency of transfer.

The results of Zander and Kogut (1995) are often taken as evidence that the speed of (voluntary) transfer is dependent on the degree of tacitness of the technological skills involved. But as they point out, there are good reasons to suppose that the causality is reversed; the sooner and the more often a firm attempts to transfer its technology to a new site, the stronger its inducements to incur the costs and effort of its articulation (cf. Simonin 1999).

However, articulation of knowledge into explicit and well-defined code does not by itself guarantee the efficient transfer of capabilities. It also requires that the recipient be familiar with it, i.e. versed in the language and theoretical worldviews of the relevant epistemic community. The cost of transfers depends both on the absorptive capacity of the recipient (Cohen and Levinthal 1990) and on the type of skill or capability that the transfer aims to provide (Hayami and Ruttan 1971).

Tacitness and Imitation. The relationship between articulation and imitation is far less clear. The threat of imitation and the mechanisms available to reduce this threat varies considerably between industries (Levin et al. 1987). The question as to whether or not articulation of knowledge increases the risk of imitation cannot be answered without reference to such differences in appropriability regimes (Teece 1987).

Although codified knowledge is more difficult to protect against theft and industrial espionage (Winter 1987, p.173; Boisot 1995, p. 47), *there is little reason to believe that articulation per se substantially increases the risk of imitation or 'leakage'.* Indeed, in Zander's study (Zander 1991; Zander and Kogut 1995), the degree of codifiability and articulability of manufacturing technology was found to be *negatively*, albeit not significantly, related to the risk of early imitation. McEvily and Chakravarthy (2002) found that 'tacitness' increased the time to imitation for major product innovations but that it significantly decreased it for minor product improvements.

There are several reasons why articulation of knowledge need not increase the hazard of imitation. First, articulated knowledge is available only to communities who master the code and the theoretical context needed to interpret the message. Second, articulated knowledge serve to inform the exercise of a skill. Usually, performance improves with practice and experience. Having access to the same codified knowledge does not automatically imply skilled execution of the practice that it informs (Winter and Szulanski 2001). As Johnson *et al.* (2002, p. 251) put it: "There will always remain irreducible differences between the skills of a heart surgeon and the code-book she uses."

Moreover, firms have many means to restrict access to codified knowledge (Liebeskind 1996). Blueprints and computer codes can be (and are) routinely locked away in company safes, employment contracts restrict employees' freedom to disclose proprietary information also after leaving the firm, etc. As Sanchez (1997, p. 173) point out, Boeing's design algorithms and procedures for aircraft simulation have been articulated and codified in computer software. However, strict security has prevented the leakage of this knowledge to competitors.

In Zander's (1991) study, the factor most strongly increasing the hazard of imitation was 'key employee turnover.' Knowledge leakage through the loss of experienced personnel is clearly an important threat. However – again excepting the possibility of direct theft – the magnitude of this risk appears to be independent of the degree of articulation of the knowledge in question. Individuals possess and can reveal both tacit and explicit knowledge.

However, as soon as knowledge becomes embodied in a product or other physical artifact it can frequently be imitated.[8] However, contrary to a common assumption, the ease with which this can be done is largely independent of the degree of articulation of the relevant design and manufacturing skills. It is primarily determined by the extent to which the relevant epistemic community extends beyond the boundaries of individual firms. In many industries, also ones characterized by highly tacit knowledge and practices, the mere demonstration that a particular product design is indeed feasible is sufficient to induce imitation.

The Advantages and Disadvantages of Articulation. As argued above, most forms of economically relevant knowledge can be articulated. Whether or not articulation will take place will be determined by the expected benefits, the value attached to these benefits and by the cost and effort required. The benefits include (1) the speeding up of innovation and knowledge creation, (2) advantages associated with division of labor (specialization, economies of scale, etc.), and (3) improved capabilities for replication and control (quality control, growth and technology transfer, etc). These benefits are typically large in relation to the costs and efforts required, especially – but not only – in modern science-based industries. Only on rare occasions will rational firms forgo these benefits to maintain the (largely imaginary) protection against imitation afforded by the tacitness of its knowledge.

Knowledge in the Theory of the Firm

The framework outlined above focuses on epistemic communities as the locus of both creation and exploitation of knowledge. It is in the mutual engagement in a common enterprise, that groups of people develop, maintain and nurture the codes, tools and theories necessary for the articulation and development of skills and capabilities. Epistemic communities provide conditions favoring communication and knowledge flows both through commonalities of language ('code') and worldviews ('theory') and by fostering the shared identities and trust necessary that facilitate cooperation and knowledge exchange.

The characteristics and configuration of the epistemic communities to which its members belong define the knowledge structure of the firm. 'The firm' itself cannot usefully be modeled as the locus of knowledge creation and learning. Rather than as single, seamless entities, firms consist of a number, possibly a large number, of epistemic communities and subcultures (Martin 1992). The ways in which these interact and the degree of antagonism or compatibility between their 'world-views' are matters that can only be established empirically; they cannot be determined by a priori reasoning alone. As Brown and Duguid, (2001b) note:

> … [W]hile accepting that firms may provide some degree of common culture for their members, it seems important to consider, for example, how much a CEO and a technician in a large Fortune 500 company really have in common, As accounts of social networks and occupational communities indicate, both are likely to have more in common with their peers in other organizations than with many of the other employees in their own. Brown and Duguid, (2001b, p. 201)

Accepting communities of practice as the critical locus for identity formation and knowledge creation brings back into focus the classic problem of how organizations can integrate differentiated units (Lawrence and Lorsch 1967; Brown and Duguid 2001a; Grant 1996, 2001). We need to move away from the utterly implausible idea that simply being employed by the same legal entity ('the firm') places people in a privileged position as regards the creation and exchange of knowledge (Brown and Duguid 2001b). As both casual observation and empirical research (Szulanski 1996) testify, except in very small organizations, this notion is patently unrealistic (Soo *et al.* 2002, p. 140 f.).

Real world firms, especially large MNCs, are more often characterized by rivalry, mutual distrust or even hostility between its constituents, than by cooperation and harmonious pursuit of common objectives. To the extent that the latter situation occurs, it is the result of hard managerial work and, often costly, coordination mechanisms (Brown and Duguid 2001b; Grant 1996, 2001).

In this conceptualization, firms gain competitive advantage, first, by accessing and nurturing the epistemic communities where critical knowledge is available or is being created, and, second, by their abilities to integrate and exploit this knowledge. Certain epistemic communities are geographically clustered and geographical proximity may confer competitive advantage by privileged access to scarce talent and other specialized resources. However, most articulation and knowledge creation takes place *within* firms, and its practitioners may thereby obtain certain unique capabilities.

These may include largely tacit creative skills. But more importantly, such capabilities are largely based on articulated theoretical insights and otherwise codified knowledge, assets capable of accumulation and therefore potential sources of sustainable competitive advantage. In the words of (Dierickx and Cool 1989, p. 1507), "… historical success translates into favourable asset stock positions which in turn facilitate further asset accumulation."

Charismatic leadership and creative engineering talent are certainly scarce, valuable and difficult-to-imitate resources (Barney 1991). But not being susceptible to articulation, they develop only slowly over time. In much recent literature, the economic significance of tacit knowledge has been oversimplified and misunderstood. As outlined in this paper, new knowledge creation takes place through articulation, in the interactive development of new codes, new tools and new theory. More research is needed on the conditions affecting this process and its social and economic effects.

---

[1] Plato's definition is not unproblematic (c.f. Gettier 1963) but will have to do for the present purpose.

[2] The human ability to perform a task without being focally aware of the underlying knowledge seems to be the basis for the curious idea that through 'internalization' (Nonaka 1991; Hedlund and Nonaka 1993; Hedlund 1994; Nonaka and Takeuchi 1995) or 'absorption' (Boisot 1995; Boisot, *et al.* 1997) explicit knowledge can be re-converted into tacit knowledge.

[3] Although, as my baby daughter reminds me, the latter are, strictly speaking, acquired skills.

[4] As elaborated below, providing focus on the essential (and ignoring the rest) is, in fact, usually one of the benefits of articulation. Weick (1999, p. 42) notes that, "… in order for people to make sense of something, they often have to ignore much that others might notice. Reality is not so much discovered as buried in the interest of sensemaking. To make sense is to focus on a limited set of cues, and to elaborate those cues into a plausible, pragmatic, momentarily useful guide for actions…"

[5] Not coincidentally, Eisenstein (1983) regards 'standardization', 'dissemination' and 'fixity' as the distinguishing characteristics of modern 'print culture,' based on the invention of moveable type and the possibility to precisely repeat word symbols in exact repeatable order. As Ivins point out, a similar revolution had occurred nearly a hundred years' earlier with the discovery of means to print exactly repeatable pictorial statements: "The exact repetition of pictorial statements has had incalculable effects upon knowledge and thought, upon science and technology, of every kind." (Ivins 1953/1969, p. 3)

[6] The concept was first developed in the field of international relations (Haas 1992) to denote communities whose members (1) share a common set of values and beliefs, (2) have common theoretical understanding regarding causalities regarding policy measures and desired outcomes, (3) have shared criteria for validity, and (4) pursue the same policy enterprise.

[7] Since they do not show distortions in measurements, drawings in axonometric or isometric perspective are more suitable to many engineering applications, such as specifying dimensions of objects to be produced. However, perspective drawings are superior in depicting the relationships of parts in a complex whole. "Perhaps…" Edgerton (1976, p 79) speculates, "… the axonometric drawing enabled the Chinese to jump ahead of the West in technology during the Middle Ages; but linear perspective surely enabled the West to move from technology to a genuine scientific revolution after the Renaissance."
[8] Sanchez (1997, p. 173), quoting Gilder (1989) cites the example of early microprocessor design, the tacit aspects of which were articulated by Professor Carver Mead, to be subsequently incorporated in computer software. Today, such software makes possible the design of microprocessors far beyond the capabilities of the human mind.

REFERENCES

Adler, P. S., R. E. Cole. 1983. Designed for Learning: A Tale of Two Auto Plants. *Sloan Manage. Rev.* **25** (Spring) 85-94.

Allen, T. J. 1977. *Managing the Flow of Technology*. MIT Press, Cambridge, MA.

Ancori, B., A. Bureth, P. Cohendet. 2000. The Economics of Knowledge: The Debate about Codification and Tacit Knowledge. *Ind. Corp. Change* **9** 255-287.

Argote, L. 1999. *Organizational Learning: Creating, Retaining and Transferring Knowledge*. Kluwer, Boston.

Balconi, M. 1997. Technological Capabilities, Learning and Codification of Knowledge. Working Paper No. 64, Dipartimento di Economia Politica e Metodi Quantitativi, Università di Pavia, Italy.

Barney, J. B. 1986. Strategic Factor Markets: Expectations, Luck, and Business Strategy. *Management Sci.* **32** 1231-1241.

_____ . 1991. Firm Resources and Sustained Competitive Advantage. *J. Manage.* **17** 99-120.

Beniger, J. R. 1986. *The Control Revolution. Technological and Economic Origins of the Information Society.* Harvard University Press, Cambridge, MA.

Berman, S. L., J. Down, C. W. L. Hill. 2002. Tacit Knowledge as a Source of Competitive Advantage in the National Basketball Association. *Acad. Manage. J.* **45** 13-31.

Boisot, M. 1995. *Information Space: A Framework for Learning in Organizations, Institutions and Culture*. Routledge, London.

_____ ., J. Child. 1988. The Iron Law of Fiefs: Bureaucratic Failure and the Problem of Governance in the Chinese Economic Reforms. *Admin. Sci. Quart.* **41** 507-527.

_____ ., D. Griffiths, V. Moles. 1997. The Dilemma of Competence: Differentiation versus Integration in the Pursuit of Learning. R. Sanchez, A. Heene, eds. *Strategic Learning and Knowledge Management.* Wiley, Chichester, 65-82.

Bowker, G. C., S. L. Star. 1999. *Sorting Things Out.* MIT Press, Cambridge, MA.

Braverman, H. 1974. *Labor and Monopoly Capital*. Monthly Review Press, New York.

Brown, J. S., P. Duguid. 1991. Organizational Learning and Communities-of-Practice: Toward a Unified View of Working, Learning, and Innovation. *Organ. Sci.* **2** 40-57.

_____ . 1998. Organizing Knowledge. *Calif. Manage. Rev.* **40** 90-111.

_____ . 2000. *The Social Life of Information.* Harvard Business School Press, Cambridge, MA.

_____ . 2001a. Structure and Spontaneity: Knowledge and Organization. I. Nonaka, D. Teece, eds. *Managing Industrial Knowledge*. Sage, London, 44-67.

_____ . 2001b. Knowledge and Organization: A Social-Practice Perspective. *Organ. Sci.* **12** 198-213.

Bunge, M. 1966. Technology as Applied Science. *Tech. Cult.* **7** 329-347.
Chandler, A. D., Jr. 1977. *The Visible Hand: The Managerial Revolution in American Business.* Harvard University Press, Cambridge, MA.
Cohen, W. M., D. A. Levinthal. 1990. Absorptive Capacity: A New Perspective on Learning and Innovation. *Admin. Sci. Quart.* **35** 128-52.
Cohendet, P., F. Creplet and O. Dupouët. 2002? Communities of Practice and Epistemic Communities: A Renewed Approach of Organisational Learning within the Firm.
Constant, E. W. 1980. *The Origins of the Turbojet Revolution.* Johns Hopkins University Press, Baltomore.
Contractor, F. 1981. *International Technology Licensing*. Lexington Books, Lexington, MA.
Cowan, R., P. A. David,D. Foray. 2000. The Explicit Economics of Knowledge Codification and Tacitness. *Ind. Corp. Change* **9** 211-253.
Daft, R. L., K. E. Weick. 1984. Toward a Model of Organizations as Interpretation Systems. *Acad. Manage. Rev.* **9** 284-295.
David, P. A., D. Foray. 1995. Accessing and Expanding the Science and Technology Knowledge Base. *STI Review* **16** 13-68.
Davidson, W., D. McFetridge. 1984. International Technology Transactions and the Theory of the Firm. *J. Ind. Econ.* **32** 253-64.
de Solla Price, D. J. 1984. The Science/Technology Relationship, the Craft of Experimental Science, and Policy for the Improvement of High Technology Innovation. *Res. Pol.* **13** 3-20.
Dierickx, I., K. Cool. 1989. Asset Stock Accumulation and Sustainability of Competitive Advantage. *Manage. Sci.* **35** 1504-1513.
DiMaggio, P. J., W. W. Powell. 1983. The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields. *Am. Sociol. Rev.* **48** 147-60.
Edgerton, S. Y., Jr. 1976. Linear Perspective and the Western Mind: The Origins of Objective Representation in Art and Science. *Cultures* **3**(3) 77-104.
_____ . 1980. The Renaissance Artist as Quantifier. M. A. Hagen, ed. *The Perception of Pictures, Volume I.* Academic Press, New York, 179-212.
Edwards, K. 2001. Epistemic Communities, Situated Learning and Opens Source Software Development. Paper presented at the 'Epistemic Cultures and the Practice of Interdisciplinarity' Workshop at NTNU, Trondheim, June 11-12, 2001.
Eisenstein, E. L. 1983. *The Printing Revolution in Early Modern Europe.* Cambridge University Press, Cambridge.
Ferguson, E. S. 1992/2001. *Engineering and the Mind's Eye*. MIT Press, Cambridge, MA.
Gettier, E. L. 1963. Is Justified True Belief Knowledge? *Analysis* **23** 121-123.
Gilder, G. 1989. *Microcosm: The Quantum Revolution in Economics and Technology.* Simon & Schuster, New York.
Grant, R. M. 1996a. Toward a Knowledge-based Theory of the Firm. *Strategic Manage. J.* **17**(Winter Special Issue) 109-22.
_____ . 1966b. Prospering in Dynamically Competitive Environments: Organizational Capability as Knowledge Integration. *Organ. Sci.* **7** 375-387.
_____ . 2001. Knowledge and Organization. I. Nonaka, D. Teece, eds. *Managing Industrial Knowledge*. Sage, London, 145-169.
_____ ., C. Baden-Fuller. 1995. A Knowledge-Based Theory of Inter-Firm Collaboration. *Acad. Manage. Best Paper Proceedings* 17-21.
Haas, P.M. 1992. Introduction: Epistemic Communities and International Policy Coordination. *Int. Organ.* **46** 1-37.
Håkanson, L. 1995. Learning through Acquisitions: Management and Integration of Foreign R&D Laboratories. *Int. Stud. Manage. Org.* **25** 121-157.

Hayami, Y., V. Ruttan. 1971. *Agricultural Development in International Perspective*. Johns Hopkins University Press, Baltimore.

Hedlund, G. 1994. A Model of Knowledge Management and the N-Form Corporation. *Strategic Manage. J.* **15** 73-90.

_____ ., I. Nonaka. 1993. Models of Knowledge Management in the West and Japan. In P. Lorange, B. G. Chakravarthy, J. Roos, H. Van de Ven, eds. *Implementing Strategic Processes, Change, Learning and Cooperation.* Basil Blackwell, London, 117-144.

_____ ., U. Zander. 1993 Architectonic and List-Like Knowledge Structuring: A Critique of Modern Concepts of Knowledge Management. Research Paper 1993/2. Institute of International Business, Stockholm School of Economics.

Hofstede, G., B. Neuijen, D. D. Ohayv, G. Sanders. 1990. Measuring Organizational Cultures: A Qualitative and Quantitative Study across Twenty Cases. *Admin. Sci. Quart.* **35** 286-316.

Ivins, W. M., Jr. 1938/1973. *On the Rationalization of Sight.* Da Capo Press, New York.

_____ . 1953/1969. *Prints and Visual Communication.* Da Capo Press, New York.

Jelinek, M. 1980. Toward Systematic Management: Alexander Hamilton Church. *Bus. His. Rev.* **54** 63-79.

Johnson, B., E. Lorenz, B.-Å. Lundvall. 2002. Why All This Fuss About Codified and Tacit Knowledge? *Ind. Corp. Change* **11** 245-262.

Knorr-Cetina, K. 1999. *Epistemic Cultures: How the Sciences Make Knowledge.* Harvard University Press, Cambridge, MA.

Kogut, B., U. Zander. 1992. Knowledge of the Firm, Combinative Capabilities, and the Replication of Technology. *Organ. Sci.* **3** 384-97.

_____ . 1993. Knowledge of the Firm and the Evolutionary Theory of the Multinational Corporation. *J. Int. Bus. Stud.* **24** 625-45.

Kreiner, K. 2002. Tacit Knowledge Management – The Role of Artifacts. *J. Knowledge Manage.* **6** 112-123.

Kuhn, T. S. 1977. *The Essential Tension.* University of Chicago Press, Chicago.

Lave, J., E. Wenger. 1991. *Situated Learning: Legitimate Peripheral Participation*. Cambridge University Press, New York.

Lawrence, P. R., J. W. Lorsch. 1967. *Organization and Environment: Managing Differentiation and Integration.* Harvard University Press, Boston, MA.

Leonard, D., S. Sensiper. 1998. The Role of Tacit Knowledge in Group Innovation. *Calif. Manage. Rev.* **40** 112- 132.

Levin, R. C., A. K. Klevorick, R. R. Nelson, S. G. Winter. 1987. Appropriating the Returns from Industrial R&D. *Brookings Pap. Eco. Ac.* pp. 783-820.

Liebeskind, J. P. 1996. Knowledge, Strategy, and the Theory of the Firm. *Strategic Manage. J.* **17**(Winter Special Issue) 93-107.

March, J. G. & H. Simon. 1958. *Organizations*. Wiley, New York.

Martin, J. 1992. *Cultures in Organizations: Three Perspectives*. Oxford University Press, Oxford.

Marx, K. n. d. *The Poverty of Philosophy.* New York

McEvily, S. K., B. Chakravathy. 2002. The Persistence of Knowledge-Based Advantage: An Empirical Test for Product Performance and Technological Knowledge. *Strategic Manage. J.* **23** 285-305.

McGee, D. (1999). From Craftsmanship to Draftsmanship. *Tech. Cult.* **40** 209-236.

Murtha, T. P., S. A. Lenway, J. A. Hart. 2001. *Managing New Industry Formation: Global Knowledge Formation and Entreprenurship in High Technology.* Stanford University Press, Stanford, CA.

Needham, J. 1978. *The Shorter Science & Civilisation in China, Volume 1*. (Abridgement of the original text by C. A. Ronan.) Cambridge University Press, Cambridge.
Nelson, R. R. and S. G. Winter. 1982. *An Evolutionary Theory of Economic Change*. Harvard University Press, Cambridge, MA.
Nonaka, I. 1991. The Knowledge-Creating Company. *Harvard Bus. Rev.* (Nov.-Dec.) 96-104.
_____ . 1994. A Dynamic Theory of Organizational Knowledge Creation. *Org. Sci.* **5** 15-37.
_____ ., H. Takeuchi. 1995. *The Knowledge-Creating Company*. Oxford University Press, Oxford.
Orr, J. E. 1996. *Talking About Machines: An Ethnography of a Modern Job.* Cornell University Press, Ithaca.
Petroski, H. 1996. *Invention by Design. How Engineers Get from Thought to Thing.* Harvard University Press. Cambridge, MA.
Polanyi, M. 1962. *Personal Knowledge: Towards a Post-Critical Philosophy*. Harper and Row, New York.
_____ . 1966. *The Tacit Dimension*. Doubleday, Garden City, NY.
Prahalad, C. K., R. Bettis. 1986. The Dominant Logic: A New Linkage Between Diversity and Performance. *Strategic Manage. J.* **7**. 485-501.
Ravetz, J. R. 1971/1996. *Scientific Knowledge and Its Social Problems*. Transaction Publishers, New Brunswick, NJ.
Reed, R.. DeFillippi, R. J. 1990. Causal Ambiguity, Barriers to Imitation, and Sustainable Competitive Advantage. *Acad. Manage. Rev.* **15** 88-102.
Rogers, C. F. C. 1983. *The Nature of Engineering. A Philosophy of Technology.* Macmillan, London.
Ryle, G. 1945-1946. Knowing How and Knowing What. *P. Aristotelian Soc.* **46** 1-16.
Sanchez, R. 1997. Managing Articulated Knowledge in Competence-based Competition. R. Sanchez, A. Heene, eds. *Strategic Learning and Knowledge Management.* Wiley, Chichester, 163-187.
Saxenian, A. 1996. *Regional Advantage: Culture and Competition in Silicon Valley and Route 128.* Harvard University Press, Cambridge, MA.
Schön, D. A. 1983/1996. *Reflective Practitioner – How Professionals Think in Action*. Basic Books, New York.
Senker, J. 1995. Tacit Knowledge and Models of Innovation. *Ind. Corp. Change* **4** 425-47.
Simon, H. A. 1955. A Behavioral Model or Rational Choice. *Q. J. Econ.* **69** 99-118.
Simonin, B. L. 1999. Ambiguity and the Process of Knowledge Transfer in Strategic Alliances. *Strategic Manage. J.* **20** 595-623.
Soo, C., T. Devinney, D. Midgley, A. Deering. 2002. Knowledge Management: Philosophy, Processes and Pitfalls. *Calif. Manage. Rev.* **44** 129-150.
Spender, J.-C. 1989. *Industry Recipes*. Basil Blackwell, Oxford.
_____ . 1996. Making Knowledge the Basis of a Dynamic Theory of the Firm. *Strategic Manage. J.* **17**(Winter Special Issue) 45-62.
_____ ., R. M. Grant. 1996. Knowledge and the Firm: Overview. *Strategic Manag. J.* **17** (Winter Special Issue) 5-9.
Star, S. L., J. R. Griesemer 1989. Institutional Ecology, "Translations" and Boundary Objects: Amateurs and Professionals in Berkley's Museum of Vertebrate Zoology, 1907-39. *Soc. Stud. Sci.* **19** 387-420.
Steinmueller, W. E. 2000. Will New Information and Communication Technologies Improve the 'Codification' of Knowledge? *Ind. Corp. Change* **9** 361-376.
Sternberg, R. J., J. A. Horvath, eds. 1999. *Tacit Knowledge in Professional Practice. Researcher and Practitioner Perspectives*. Lawrence Erlbaum Associates Mawah, NJ.

Subramaniam, M. and N. Venkatraman. 2001. Determinants of Transnational New Product Development Capability: Testing the Influence of Transferring and Deploying Tacit Overseas Knowledge. *Strategic Manage. J.* **22** 359-378.

Szulanski, G. 1996. Exploring Internal Stickiness: Impediments to the Transfer of Best Practice Within the Firm. *Strategic Manage. J.* **17** 27-43.

Teece, D. J. 1977. Technology Transfer by Multinational Firms: The Resource Cost of Transferring Technological Know-how. *Econ. J.* **87** 242-61.

_____ . 1987. Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy. D. J. Teece, ed. *The Competitive Challenge - Strategies for Industrial Innovation and Renewal.* Harper & Row, New York.

Tsoukas, H. and E. Vladimirou 2001. What is Organizational Knowledge? *J. Manage. Stud.* **38** 973-993.

Vincenti, W. G. 1990. *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History*. Johns Hopkins University Press, Baltimore.

Wagner, R., R. Sternberg 1985. Practical Intelligence in Real World Pursuit: The Role of Tacit Knowledge. *J. Pers. Soc. Psychol.* **49** 436-458.

Watson, J. D. 1968. *The Double Helix.* Weidenfeld & Nicolson, London.

Weick, K. E. 1995. *Sensemaking in Organizations*. Sage, Thousand Oaks, CA.

_____ . 1999. Sensemaking as an Organizational Dimension of Global Change. D. L. Cooperrider, J. E. Dutton, eds. *Organizational Dimensions of Global Change. No Limits to Cooperation.* Sage, Thousand Oaks, CA, 39-56.

Wenger, E. 1998. *Communities-of-Practice. Learning, Meaning and Identity.* Cambridge University Press, Cambridge.

White, J. B. 1990. *Justice as Translation*. University of Chicago Press, Chicago.

Winter, S. G. 1987. Knowledge and Competence as Strategic Assets. D. J. Teece, ed. *The Competitive Challenge - Strategies for Industrial Innovation and Renewal.* Harper & Row, New York.

_____ ., G. Szulanski. 2001. Replication as Strategy. *Org. Sci.* **12** 730-743.

Wright, R. W. 1997. Tangible Integration versus Intellectual Codification Skills: A Comparison of Learning Processes in Developing Logic and Memory Semiconductors. R. Sanchez, A. Heene, eds. *Strategic Learning and Knowledge Management.* Wiley, Chichester, 83-100.

Yates, J. 1989. *Control through Communication. The Rise of System in American Management.* Johns Hopkins University Press, Baltimore.

_____ 1990. For the Record: The Embodiment of Organizational Memory, 1850-1920. *Bus. Econ. Hist.* **19** 172-182.

Zander, U. 1991. *Exploiting a Technological Edge - Voluntary and Involuntary Dissemination of Technology*. Doctorial dissertation. Institute of International Business at the Stockholm School of Economics, Stockholm.

_____ ., B. Kogut. 1995. Knowledge and the Speed of Transfer and Imitation of Organizational Capabilities: An Empirical Test. *Organ. Sci.* **6** 75-92.

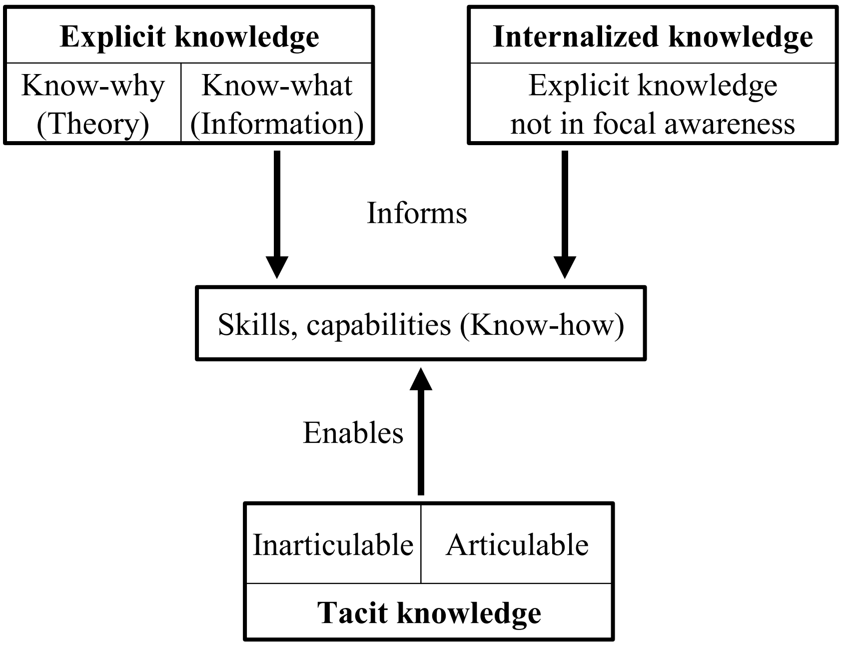

FIGURE 1.

Skills, Tacit and Explicit Knowledge

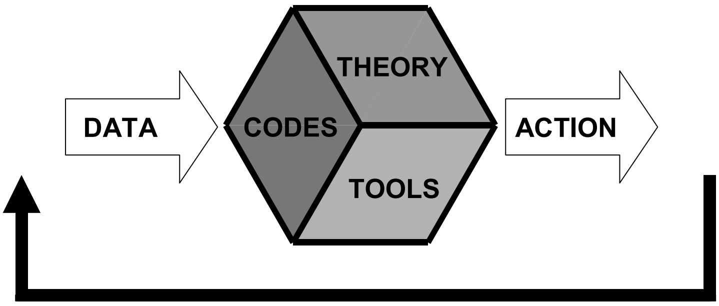

FIGURE 2.

The Functional Elements of Epistemic Communities (adapted from Daft and Weick 1984).

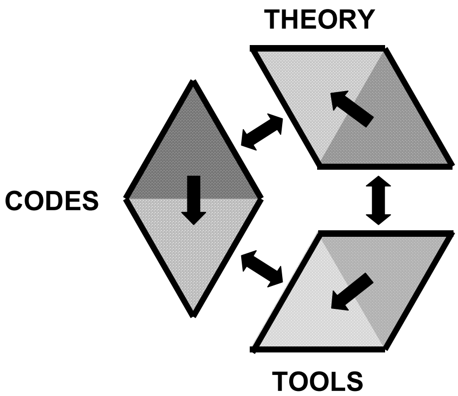

FIGURE 3.
The Articulation Circle