FROM TACIT KNOWLEDGE TO SCIENTIFIC THEORY:

THE POWER AND LOGIC OF ARTICULATION

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Abstract

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.

The costs and mechanisms of articulation differ between different kinds of knowledge. The paper outlines a taxonomy of tacit knowledge and a model of articulation. These are applied in a discussion of the incentives that induce firms to articulate their knowledge. It is argued, first, that most forms of economically relevant knowledge can be articulated. The only major exception is the creative skills and capabilities of innovation and entrepreneurship. Second, the benefits of articulation are typically large in relation to the cost and effort required. Indeed, the progressive articulation and codification of craftsmanlike skills is a distinct characteristic of industrialization and the evolution of modern society. Third, articulation does not, as a rule, increase the hazard of imitation nor does the possession of unarticulated, tacit knowledge per se provide a basis for competitive advantage.

These conclusions suggest that the economic significance of tacit knowledge has been oversimplified and perhaps overestimated in recent literature. Before the concept of knowledge can be made the basis for a new theory of the firm, more research is needed on the conditions affecting the process of articulation and its effects on the competitiveness of firms.

(*Tacit Knowledge; Articulation; Imitation)*

> 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, G., "A Model of Knowledge Management and the N-Form Corporation," *Strategic Management Journal*, 1994, Vol. 15, p. 76)

In reviewing the recent literature on strategy and organization, one cannot help but be struck by the frequent invocation of 'tacit' knowledge, 'tacit' technologies and 'tacit' skills as factors explaining observed (or assumed) behavior, competitiveness, strategy, etc. It has become increasingly *en vogue* to emphasize the tacit and 'sticky' nature of knowledge (von Hippel 1994; Szulanksi 1996; Brown and Duguid 1998) over its explicit and easily communicable forms, relegating the continued effort at better articulation, as in expert systems and artificial intelligence, to the realm of 'overhype' (Spender and Grant 1996, p. 6).

'Tacitness', it seems, is capable of explaining a whole range of phenomena. Access to tacit knowledge requires insider status and geographical proximity – hence, the assumed importance of the 'home base' for the competitiveness of multinational companies (Porter 1986, 1990; Sölvell and Zander 1994, 1995). The degree of tacitness of manufacturing technologies determines the ease and cost of their transfer both within multinationals and to third parties (Kogut and Zander 1992, 1993). Tacit knowledge is assumed to be difficult to imitate (Nelson and Winter 1982, pp. 123 f.). Its possession may therefore be an important source of competitive advantage. Indeed, the existence of proprietary tacit skills and knowledge is increasingly seen as a fundamental determinant of the very existence and boundaries of firms (Kogut and Zander 1993; Grant 1996; Spender 1996; Conner and Prahalad 1996).

Equally striking, however, is the almost total absence of studies attempting to refine and empirically verify these concepts. As Kogut and Zander (1992, p. 383) note, "... the idea of tacit knowledge has been widely evoked but rarely defined." In much of the literature, the reader is offered little more by way of explanation than the obligatory reference to Polanyi's (1966, p. 4) dictum - "we can know more than we can tell".

The most notable attempt to measure different aspects of tacitness and to determine their significance for the transfer and imitation of technology is that of Zander (Zander, 1991; Zander and Kogut, 1995), drawing on Winter's (1987) taxonomy of knowledge assets. These studies explicitly recognize that there are several dimensions to tacit knowledge, but these are offered without much compelling theoretical argument.

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 fact is somewhat peculiar, since, as Spender (1996, p. 51) notes:

> ...the modern trend is away from the tacit and towards the explicit, from craft to system. Thus firms increasingly use explicit objectified knowledge, whether that be science or established standards and practices, and become increasingly dependent on the conscious knowledge of their employees, and on their scientific and technical training.

This paper is an attempt to redress this imbalance. It is based on the assumption that most forms of economically significant knowledge can be articulated and codified. Whether or not such articulation will take place depends on costs and incentives:

> Whether a particular bit of knowledge is *in principle* articulable or necessarily tacit is not the relevant question in most behavioral situations. Rather, the question is whether the costs associated with the obstacles to articulation are sufficiently high so that the knowledge *in fact* remains tacit. (Nelson & Winter 1982, p. 82, emphasis in the original.)

The costs and mechanisms of articulation differ between different kinds of knowledge. In order to analyze the conditions under which articulation is likely to take place it is necessary to distinguish more clearly than is usually done, the nature and characteristics of different kinds of tacit knowledge. To this end, the paper first outlines a taxonomy of tacit knowledge to serve as a basis for an analysis of the conditions affecting its articulation. The framework thus developed is then applied in a discussion of the incentives that induce firms to articulate their knowledge. It is argued that the benefits are substantial and that articulation is nearly always a value-creating activity. The final section addresses a possible objection to this line of argument: the proposition that articulated knowledge is more liable to imitation by competitors, thus reducing its potential value. It is shown that with few, albeit important, exceptions this is not so.

The Nature of Tacit Knowledge

It is a curiosity of the English language that the word 'to know' makes no distinction between knowledge of facts and relationships ('substantial knowledge', know what) and knowledge as skills ('procedural knowledge', know how). For Polanyi (1966, p. 7), whose main interest is a critique of positivist theory of science, this distinction 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."

However, failure to make this distinction obscures the fact that skills and substantive knowledge have different characteristics and economic implications. The latter derives its primary[1] economic significance only through *application* in the performance of an economically meaningful activity, i.e. the exercise of a skill. More 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.

Discussions of tacit knowledge typically proceed from Polanyi's observation "*...that 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*." (1962, p. 49, italics in the original) This is sometimes taken as a rationale for defining tacit knowledge as knowledge that is not capable of articulation and codification (see, e.g., Grant 1996). Similarly, the first dimension of Winter's (1987, p. 170) taxonomy of knowledge assets ranges from "highly tacit" to "highly articulable", suggesting that 'highly tacit' knowledge is not articulable and, in its extreme forms, not communicable.[2]

This semantic convention, however, disregards the second part of Polanyi's definition. Of course, it is not uncommon that a person exercising a skill may not be able to provide a useful account of the rules that he observes. The knowledge underlying the skill is then tacit. However, this does not preclude the possibility that – following a certain investment of time and energy – he may, at a later time, be able to do so. The rules have then been made explicit.

In fact, most of the examples of tacit knowledge offered by Polanyi are of this nature.[3] Thus, his often quoted examples of tacit skills, swimming and bicycle riding, are both offered together with the corresponding articulated rules. They are tacit only in the sense that they are not usually articulated. The rules governing the riding of a bicycle, for example, can, as Polanyi shows, be articulated:

> 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 pres-

> ently 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)

Of course, this does not imply that all skills are indeed articulable. Polanyi's choice of examples may rather be taken as evidence of the impossibility to capture in language the nature of 'truly tacit' knowledge. There are good reasons to believe that human beings have access to faculties – such as that of speech and use of grammar – that are not accessible to consciousness, and can therefore not be articulated (Chomsky, 1986). However, the analysis of these and other "natural" human faculties, although significant in areas such as neurology, linguistics and philosophy, would seem to fall outside the realm of economic enquiry.

Most tacit skills of economic interest are at least potentially articulable. These include both simple technical skills – the motoric of riding a bicycle – and more complex ones – such as the skills of a master craftsman – which include also a tacit cognitive dimension. As stated by Nonaka & Takeuchi (1995, p. 8), the cognitive dimension of tacit knowledge

> ... consists of schemata, mental models, beliefs, and perceptions so ingrained that we take them for granted. The cognitive dimension of tacit knowledge reflects our image of reality (what is) and our vision for the future (what ought to be). Though they cannot be articulated very easily, these implicit models shape the way we perceive the world around us.

It can be assumed that most forms of tacit cognitive knowledge can – if only with difficulty – be articulated. An important exception to this rule are creative skills, skills required to conceive of and do new things.[4] This applies equally to scientific discovery as to the engineer's conception and design of a new machine. In science, there is a fundamental difference between the logic of discovery and the logic of demonstration.[5] 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. In engineering, many design decisions contain a fundamental element of tacit, non-verbal thought and reasoning (Ferguson, 1977; Senker 1995). This element becomes greater the greater the degree of novelty or invention involved (Layton 1974).

For the ‘early’ Schumpeter, the creative ability to envision and realize new things (‘new combinations’) without the aid of prescription and prior experience is one of the distinguishing characteristics of the entrepreneur, setting him/her apart from other economic subjects.

> What has been done already has the sharp-edged reality of all the things which we have seen and experienced; the new is only the figment of our imagination. Carrying out a new plan and acting according to a customary one are things as different as making a road and walking on it.
>
> Here the success of everything depends on intuition, the capacity of seeing things in a way which afterwards proves to be true, even though it cannot be established at the moment, and of grasping the essential fact, discarding the unessential, even though one can give no account of the principles by which this is done. (Schumpeter, 1934/1997, p. 85)

Although psychologists have developed techniques that purportedly aid creative thinking, the art of discovery cannot be prescribed and codified. However, it can be passed on from master to apprentice:

> …the 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 proposition that creative, innovative activity is based largely on tacit skills is therefore not in contradiction to the ‘late’ Schumpeter’s (1942/1975) claim that, during the twentieth century, innovation has become routinized in the R&D laboratories of large corporations. It is quite possible that organizations can develop ‘routines’ for innovative activity based on inarticulable tacit skills and that these routines can be passed on to new members. Moreover, technological improvements *within* established technological paradigms can often be obtained following well-defined, codifiable routines (Dosi 1988; Nelson and Winter 1982, pp. 132 f).

Table 1 summarizes the argument in the form of a simple taxonomy. It suggests that – with the exception of certain creative skills and neurologically determined human faculties – most economically relevant tacit knowledge is both articulable and codifiable.

Table 1.
A Taxonomy of Skills and Knowledge

Not articulable		
Technical	Neurologically determined faculties, inaccessible to consciousness	Human faculties of speech, sense perception, etc.
Cognitive	Creative skills	Art, innovation
Articulable but usually tacit		
Technical	Motoric skills	Riding a bicycle
Cognitive	Mental maps, implicit "theories", unarticulated beliefs and values, etc.	Rules of thumb, organizational culture
Articulable and usually codified		
Technical	Technical skills	Operating a computer
Cognitive	Scientific theory	Quantum physics

Articulation

'Articulation' is the process of transforming tacit knowledge 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.) Although linguistically awkward, it is possible, and at times helpful, to regard also physical artifacts, such as machines, as a form of articulated knowledge.

Articulation is not always useful nor economically meaningful. "...[M]axims can serve as a guide to an art only if they can be integrated into the practical knowledge of the art." (Polanyi, 1962, p. 50) The reason is that articulation is always incomplete. In articulation, some of the 'richness' of the original knowledge is inevitably lost. Sometimes, this loss has serious consequences. For all practical purposes, the explicated rules of bicycle riding are useless. The same applies to a whole range of personal skills, i.e. skills that can only be mastered by trial and error and where knowledge of the underlying rules does not facilitate learning. However, the economic significance of this class of skills appears distinctly limited:

> 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)

As Balconi (1997, p. 22) notes, advances in the fields of electronics, computer science and scientific instruments have dramatically reduced the costs of articulation. However, skills that are easily learnt by trial-and-error or a short period of apprenticeship may still not warrant the cost of codification. Indeed, the fact that some activities requiring tacit skills remain also in very modern production plants is evidence of their relative lack of economic importance.

In many other instances, articulation – precisely because it conveys only a part of the original knowledge or skill – may help focus attention on its critical aspects. This explains, for example, the productivity increases obtained with the help of time-and-motion studies in the tradition of Fredrick W. Taylor. It also helps to account 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)

Codes

Clearly, some forms of knowledge can be symbolically more easily represented in certain codes than in others. Effective articulation may, in fact, require the development of dedicated codes and may be impossible in their absence. The programming language BASIC may be well suited to express certain (simple) rules but becomes unwieldy when applied to more complex ones (Papert, 1979 in Kogut & Zander 1992, p. 391).

Thus, some forms of tacit knowledge may appear to be near impossible to articulate not because they are inherently inarticulable but because appropriate codes are not available. 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 (Jones, 1970; Ferguson 1977; McGee, 1999).

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 & Zander 1992, p. 386 f.) Transfer of codified information, therefore, appears unproblematic as long as the recipient is in possession of the code required to decipher the message. However, the existence of a shared code cannot always be assumed. Codes – like the knowledge they express – have both tacit and explicit dimensions.

It is well known that members of organizations tend to develop idiosyncratic coding schemes, reflecting the their common, generally tacit, interpretation of the world and their own roles within it.[6] Such coding schemes enhance the efficiency of communication among organizational members but may impede communication with 'outsiders'. (Allen 1977) Like other aspects of organizational culture, local codes tend to be taken for granted and their mastery is largely tacit. The tacit character of codes frequently aggravates the problem of communication across organizational boundaries:

> There is a great deal of overlap among the coding schemes of different organizations operating within the same culture. On the other hand, the nonoverlapping areas, however small, can potentially operate to produce semantic noise, and they can be even more troublesome because it can go undetected. (Allen 1977, p. 139)

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 be familiar with it. 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.[7]

This is clearly not always the case. According to Allen, R&D engineers rarely consult professional engineering journals for the reason that these

> ...are utterly incomprehensible to the average engineer. They often rely heavily on mathematical presentations, which can be understood only by a limited audience. The average engineer has been away from the university for a number of years and has usually allowed his mathematical skills to degenerate. (Allen 1977, p. 73.)

To summarize, codes differ in the degree to which they are explicit, well known, accepted and easy to learn. This fact seems to underlie the concept of '*teachability'*, as one dimension of tacitness (Winter 1987, Zander & Kogut 1995). Some pieces of information can be transferred in codes that are generally learnt as part of a typical primary school curriculum, e.g. the conventions of writing the local language. Others may require more advanced general education and yet others are learnt in specialized programs in academic or vocational training institutions.

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 (Nonaka & Takeuchi 1995, p. 58). Polanyi's explication of the rules governing the art of riding a bicycle is meaningless without at least some, if only intuitive, knowledge of inertial forces and Newton's first law.

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 national or organizational culture. According to one of many definitions (Smircich, 1983), the latter include

> ...the deeper level of basic assumptions and beliefs that are shared by members of an organization that operate unconsciously, and that define in a basic 'taken-for-granted' fashion an organization's view of itself and its environment. These assumptions and beliefs are learned responses to a group's problems of survival and to problems of internal integration. They come to be taken for granted because they solve those problems repeatedly and reliably. (Schein 1985, p. 5 f.)

Organizational culture includes the habits, conventions and traditions that shape day-to-day organizational practice.[8] These are acquired by new members of the organization through situated learning in a process described by Lave & Wenger (1991) – in explicit analogy to the master-apprentice relationship – as 'legitimate peripheral learning'. Learning from this viewpoint is the process of becoming an 'insider':

> Learners do not receive or even construct abstract, "objective," individual knowledge; rather, they learn to function in a community. They acquire that particular community's subjective viewpoint and learn to speak its language. Learners are acquiring not explicit, formal "expert knowledge," but the embodied ability to behave as community members. (Brown & Duguid 1991, p. 48)

Working groups, 'communities-of-practice,' share the same tacit skills, codes and cognitive schemata. These shape actual ('noncanonical') practice that may significantly differ from the espoused (‘canonical’) practice (as codified in manuals, organization charts, etc. (Brown & Duguid 1991). Moreover, communities-of-practice tend to develop their

> ...own criteria for what counts as evidence and what provides “warrants” – the endorsements for knowledge that encourage people to rely on it and hence make it actionable. (Brown and Duguid, 1998, p. 99)

Thus, it is argued, knowledge (both explicit and tacit) tends to flow easily within communities of practice but only with difficulty between different communities.

Because of their social origin, collective work practices and other significant elements of organizational culture are often ambiguous and socially complex. Organizational cultures are often highly idiosyncratic, reflecting not only the unique personalities of their founders and the people who work there (Barely 1983; Laurent 1986) but also the unique historical circumstances that the organization has encountered and learned to cope with. On these grounds, it is sometimes assumed that the values, beliefs and habits embedded in organizational are beyond analysis, must therefore remain tacit and cannot be explicated in economically significant ways (Lippman & Rumelt, 1982).[9]

It is undoubtedly true that organizations display unique cultural traits. These find symbolic expression in a range of different ways, including vocabulary, office design and dress codes as well as beliefs and values supported and legitimated in rituals and myths (Pettigrew 1979). Since they influence perceptions and work practices they have significant functional consequences. However, it seems that superficially very different organizational cultures, belief systems, etc. can support very similar outcomes in terms of economic performance. As institutionalization theory emphasizes, focussing on differences obscures fundamental commonalities between organizations facing similar environments.

Organizations that face the same or similar sets of technical and environmental conditions tend to respond in similar ways and assume similar structures. (DiMaggio & Powell, 1983.) Through competition and selection and through various mechanisms of isomorphic change (Scott 1994), over the long run, communities of practice with essentially similar characteristics can be expected to emerge, not only within the firms of an industry, but also in other types of 'organizational fields.' Of particular importance, especially in so called knowledge based industries employing highly educated specialists, is the effect of 'normative isomorphism' associated with professionalization (DiMaggio & Powell 1983, p. 152). This includes the effects of selection, socialization and training in the educational system, leading to

> ... a 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 & Powell, 1983, p. 152.)

Associated with the creation and legitimization of a common cognitive base are the emergence and growth of professional networks spanning organizational boundaries. Due to such networks and the development of communication technologies knowledge sometimes travels more easily between organizations than between 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 & Duguid, 1998, p. 102).

The cognitive and other dimensions of organizational culture are rarely articulated. They are typically 'taken-for-granted' and only in special circumstances – such as in the wake of mergers and acquisitions – made explicit. However, as argued above, the significance of such cultures as impediments for articulation should not be overstated.

Moreover, most forms of tacit knowledge evolve in communities of practice not confined by organizational boundaries. As argued below, this has significant consequences for the ease or difficulty of imitation.

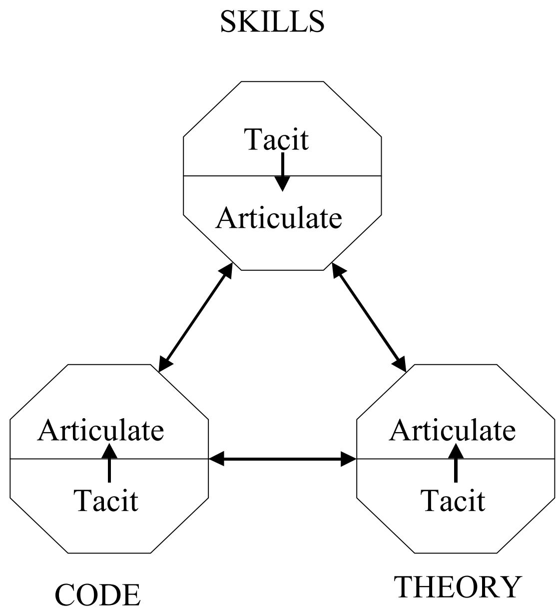
Towards a Model of Articulation

In the process of articulation, 'skills' 'codes' and 'theory' interact in significant and complex ways (Figure 1). The development of the one influences the development of the other. A striking illustration is offered by McGee (1999), in his discussion of the impact of measured multiview plans (the 'code') on shipbuilding (the 'skill') through the development of a coherent body of knowledge (the 'theory') regarding the relationship of between various aspects of a ship's design (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)

The articulation of tacit knowledge requires, first, its translation into communicable code. This requires effort, especially when there is no suitable code available, in which case the code itself must first be invented and developed. Second, the coded message must be meaningful. Messages derive meaning by being placed in relationship to previously acquired knowledge. Tacit or explicit, as theory or myth, this knowledge provides the 'frame-of-reference' ('theory') within which the message is interpreted. New knowledge and, hence, new skills are created through the interaction of skills, codes and theory.[10]

Figure 1
The Elements of Articulation



As illustrated in the debate over the relationship between science and technology, the impetus for this 'articulation circle' sometimes comes from the emergence of new skills, sometimes through the development of new and more powerful codes, and, sometimes through the 'independent' development of theory. However, the development of new skills, new codes and new theory all require effort and are costly. They will only be undertaken if they are expected to generate benefits in excess of these costs. However, given such inducements the process will draw on both tacit and explicit elements (Nonaka & Takeuchi 1995). As Sanders (1996, p. 50) notes, "The boundary between the explicit and tacit types of knowledge is both porous and flexible, the there is traffic between the domains."

The 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. The specific inducements for undertaking the investment necessary for articulation have differed over time and between contexts, but seem to fall in three categories: *division of labor, innovation,* and *replication*.

Whether or not these benefits are being sought depends not only on the expected costs and the expected probability of their realization. They will also be influenced by the value attached to the potential benefits.

Division of Labor

One of the primary benefits 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 spent in production. This limits the number of apprentices that a master can supervise at any one time and, thereby, limits his opportunity to exploit advantages of specialization and division of labor. In pre-industrial Europe, these limits were reinforced also by the institutional setting of the time, e.g. in the rules of guilds and the moral sanctions of the church.

As noted above, one of the first steps in articulation was the Renaissance development of design-by-drawing, later extended to the use of measured drawings, specifying the dimensions of products before their actual production (Jones 1970). This type of articulation had several consequences for the division of labor. First, 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. Second, the use of measured drawings made it possible to devise, plan and execute projects – such as large ships of buildings – that were to big for a single craftsman to make. (McGee 1999.) Thus, one of the benefits of articulation – in the form of drawings or in modern day PERT charts – is to permit the execution of more complex tasks. Equally important, by enhancing division of labor and specialization, articulation can lead to dramatic improvements in productivity.

A further economic inducement is the 'downskilling' frequently associated with articulation. Thus, the advantage of time-and-motion studies in the scientific management tradition is not only to increase the productivity of the individual worker. At least as important is the transformation of work itself, from skilled or semi-skilled craft production to unskilled manufacturing jobs, and the resultant saving in wage costs.

However, since codification is always incomplete, articulation of skills can be problematic. This is vividly illustrated in Orr's studies (1996, quoted from Brown and Duguid 1991) of service technicians at Xerox. Here, the skills required to repair a malfunctioning copying machine were codified in a set of manuals, in essence providing a decision tree for diagnosis and repair. The aim was to simplify the repairman's work and to reduce the amount of training he/she would require to perform the job. In actual practice, however, copying machines regularly broke down in ways different from and more complex than those envisaged in the manuals. In order to be able to perform their jobs 'service reps' had to develop a communal set of 'noncanonical' practices, passed on in the form of 'war stories' about the defeat of especially malicious machines (Brown and Duguid 1991).

Innovation

One of the most powerful effects of articulation is to enhance the possibilities for experimentation and innovation. In the absence of such articulation, 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. (McGee 1999, p. 216.) Should the design fail, the craftsman stands the risk of having wasted the time, work and materials involved. In consequence, craft production is inherently conservative, characterized by a very slow rate of innovation and change. Articulation through the use of drawings sped up innovation by allowing the designer to experiment with the geometrical aspects of a proposed design without the costs and effort of altering the product itself. (Jones 1970, p. 22)

A second important consequence of articulation is to increase the level of complexity that can be managed. Codification makes it possible to 'chunk', store and communicate technological knowledge (Simon 1974). This too is exemplified in the use of drawings, which enabled designers to deal with a hitherto "unmanageable, and unimaginable, degree of complexity." (Jones 1970, p. 28.)

In Winter's (1987) discussion, 'complexity' – loosely defined as "the amount of information required to characterize the item of knowledge in question" – is one of the characteristics of knowledge assets assumed to influence transferability and imitability (Winter 1987, p. 172)[11] To the extent that articulation is associated with higher levels of complexity, we should expect an inverse relationship between the degree of articulation and complexity. As Balconi (1997, p. 24) suggests, there are good reasons to believe that "a general tendency is underway whereby technologies are increasingly articulated and complex."

Of course, codification of designs is only one step in articulation and does not necessarily imply a theoretical understanding of the principles underlying a workable design. 'Technology', as Rosenberg notes,

> ... is a knowledge of techniques, methods, and designs that work, and that work in certain ways with certain consequences, even when one cannot explain exactly why. Indeed, if the human race had been confined to technologies that were understood in a scientific sense, it would have passed from the scene long ago. (Rosenberg 1982, p. 143)

Even today, technologies differ widely in the extent to which they rely on systematic, codified theory. Since such articulation is costly, many still have a large tacit component. 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 often appear that cannot be solved with established routines. Competitive advantages may then accrue to those firms that have the competence and insight to articulate product and process technologies through application of scientific method (Senker, 1995, p. 430).

Thus, especially during the later stages of an industry's technological development, companies may gain considerable benefits from systematic articulation of their manufacturing technologies (Utterback & Abernathy. 1975). This is illustrated by the experience of a Swedish engineering firm, with which the author had contact many years ago. Although the company had successfully developed and extended its product range over many decades, the underlying know-how had remained largely tacit or, as one manager described it, 'black magic.' By the mid 1980s, it had become increasingly evident that with each new generation of product the marginal increase in performance was becoming progressively smaller and could be obtained only through ever increasing time and effort. It appeared that the technological opportunities of the established trajectory had been exhausted (Dosi 1988). In response, the company decided to set up a research project, with the aim of articulating the *scientific principles* governing the operations of the product. After about two years of intensive effort, the project proved successful. It now became possible to theoretically model and to determine quantitatively the interaction of significant design parameters and central product performance properties. With this new knowledge, the company was able to dramatically improve its R&D processes, leading to a number of significant patents.[12]

As the story illustrates, tacitness is not an intrinsic property of technology. The degree of tacitness of technological knowledge is determined by the extent to which investments in its articulation have been undertaken. The decision as to whether or not to engage in such investments will be determined by the expected benefits, the value attached to these benefits and by the cost and effort required. Historically, the costs of articulation have decreased dramatically through the development of new codes, new theory and new methods of measurement. The range of articulated knowledge continues to increase.

In view of the apparent power of scientific articulation in technological development, it is interesting to ponder why technological regimes relying on large portions of tacit, firm specific knowledge persist (Metcalfe & Gibbons, 1989). As suggested above, a part of the answer is the tendency of organizations and people to search for new solutions in the vicinity of familiar and proven ones. (March and Simon 1958.) Moreover, established value systems and beliefs can form formidable obstacles to change. Following the acquisition of an American competitor active in an adjacent field, the Swedish company set up a parallel research project with the aim of reaching similar level of theoretical understanding of design principles in the U.S. subsidiary. This endeavor met with great skepticism in the acquired R&D unit, where the prestige and status of engineers were based on the possession of 'intuition' based on many years of design by trial-and-error. The Swedes remain convinced of the potential of the scientific approach, but have yet to demonstrate its superiority.

Replication

A common incentive for articulation and codification is to reduce the cost of knowledge transfer. In a seminal work, Teece (1976, 1977) demonstrated empirically that the costs of international technology transfers are often considerable, ranging in his sample from 2-59% of total project costs. Transfer costs are influenced by the sender's experience with prior transfers and with the technology, by the skills and experience of the receiver and by the characteristics of the technology itself. These results and those of Contractor (1981) and Davidson & McFetridge (1984) on technology transfers to licensees strongly suggest that investment in articulation and codification are affected by how frequently a particular technology is a candidate for transfer (Kogut & Zander, 1993). While emphasizing that tacitness of information is only one among several possible causes of high transfer costs, von Hippel (1994) suggests that a similar logic applies to the transfer of information as part of innovation-related problem solving.

Articulation and Imitation

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 knowledge transfer 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 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. As formulated by Spender and

Grant 1996, p. 8), the basic proposition is that "...knowledge which is embodied in individual and organizational practices.. cannot be readily articulated. Such knowledge is of critical strategic importance because, unlike explicit knowledge, it is both inimitable and appropriable."

As argued above, both theoretical arguments and empirical evidence lend good support to the proposition that – all things equal – the cost and difficulty of voluntary knowledge transfer decrease with its degree of articulation.[13] However, such transfers are also dependent 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.[14]

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).

In a few industries, property rights in knowledge – patents, copyrights and trade secrets – provide efficient protection against imitation. Since tacit and undeveloped knowledge is not eligible for such protection, firms operating under tight appropriability regimes have an inducement to articulate and codify their knowledge. This is the case, for example, in the pharmaceutical industry, where patent protection tends to be very efficient.

However, tight appropriability through property rights is the exception rather than the rule. In most industries, other mechanisms of appropriating the returns of innovation are more important. (Levin *et al*. 1987) These include complementary investments in sales and service (Teece 1987), first mover advantages and the ability to move down the learning curve faster than competitors.

In view of the powerful incentives for articulation outlined above, the relative importance of well-articulated, codified knowledge can be expected to increase over time. However, firms have many means to restrict access to such knowledge (Liebeskind 1996). Thus, 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.

Although codified knowledge is more difficult to protect against theft and industrial espionage (Winter 1987, p.173), *there is little reason to believe that articulation per se substantially increases the risk of imitation*. 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. Unsurprisingly, the factor most strongly increasing this risk 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.

The only form of articulation likely to increase the hazard of imitation is articulation embodied in a product or other physical artifact. In Winter's taxonomy, this aspect is captured in the concept of 'observability,' i.e. "... the extent of disclosure of underlying knowledge that is necessitated by use of the knowledge.” (Winter 1987, p. 172.) A high degree of observability obtains, for example, when the principles underlying the design of a product can be deduced by means of inspection and reverse engineering.

Contrary to a common assumption, the ease with which an observer can accomplish this task is independent of the degree of articulation of the relevant design and manufacturing skills. It is determined by the extent to which the relevant ‘community-of-practice’ 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. Such imitation need not imply a one-to-one correspondence in capabilities. As Zander (1994, p. 22) notes, “... imitation does not require the exact copying of existing know-how... innovations can be introduced and manufactured in different ways.”

Summary and Conclusions

The arguments advanced in this paper can be summarized as follows: First, most forms of knowledge underlying the skills and capabilities of firms and other economic agents can be articulated. The only major exception to this statement concerns the skills and capabilities of innovation and entrepreneurship. Second, the benefits of articulation are typically large in relation to the cost and effort required. Indeed, as noted in the epigraph of this paper, the progressive articulation and codification of craftsmanlike skills is a distinct characteristic of industrialization and the evolution of modern society. Third, articulation does not, as a rule, increase the hazard of imitation nor does the possession of unarticulated, tacit knowledge *per se* provide a basis for competitive advantage.

These conclusions suggest that the economic significance of tacit knowledge has been over-simplified and overestimated in recent literature. Before the concept of knowledge can be made the basis for a new theory of the firm, more research is needed on the conditions affecting the process of articulation – including its limitations.

Notes

[1] Of course, a person may possess substantial knowledge without the possibility (as in the case of knowledge having become obsolete) or intention (as in the case of knowledge acquired for intellectual enjoyment) of putting it to economic use.

[2] A similar common error is to equate tacit knowledge with knowledge that is difficult or expensive to articulate. This is not so. As argued below, tacit knowledge is knowledge that has not yet been articulated. Whether or not and, if so, at what cost such articulation is possible is a separate issue.

[3] Implicitly, it seems, Polanyi's choice of examples confirms (albeit in a different context) Wittgenstein's dictum "Wovon man nicht reden kann, darüber muß man schweigen"

[4] At best, tacit knowledge relevant to creation can be expressed through the use of metaphor, analogy or other forms of figurative language (Nonaka and Takeuchi, 1995). However, this is different form of articulation than the one discussed here.

[5] This distinction is a main thrust in Polanyi's argument: "...while *the articulate contents of science* are successfully taught all over the world in hundreds of new universities, the *unspecifiable art of scientific research* has not yet penetrated many of these. (Polanyi, 1965, p. 53)

[6] Polanyi emphasizes the dependence of codes on cultural tradition: "In learning to speak, every child accepts a culture constructed on the traditional interpretation of the universe, rooted in the idiom of the group to which it was born..." He also notes how this impedes communication. "Different vocabularies for the interpretation of things divide men into groups which cannot understand each other's way of seeing things and acting upon them. For different idioms determine different patterns of possible emotions and actions." (Polanyi 1962, p. 112)

[7] In this vein, von Hippel (1994) includes such costs in his definition of stickiness', which is defined in terms of the *total* incremental costs of transferring information from one point to another, i.e. including costs due to the inefficiency of the information seeker but also attributes of the information provider.

[8] Indeed, some writers have argued that 'organizational practice' is what constitutes organizational culture and that fundamental assumptions and beliefs belong in the realm of national culture (c.f. Laurent (1986) and Hofstede *et al.* ,1990).

[9] In contrast, many students of organizational culture base their research on the opposite premise, i.e. that it is both possible and helpful to identify critical elements of organizational culture - those believed to help sustain superior financial performance (Peters & Waterman, 1982; Deal & Kennedy, 1982). However – given the current state-of-the-art in social engineering – the usefulness of doing so is open to doubt (Barney 1986).

[10] The word 'theory' is here used as a shorthand for more cumbersome expressions. It should be taken to include all forms of mental schemata, such as myths and other forms of cultural tradition.

[11] As Winter (1987, p. 172 f.) himself notes, the 'complexity' of an item of knowledge may vary between different contexts. Although intuitively appealing, the concept is difficult to define and identify (Zander 1991, p. 149; Kogut and Zander 1993, p. 633).

[12] These patents refer to specific designs; the 'laws of nature' uncovered in the research are not patentable. However, neither the scientific principles nor knowledge of the success of the new approach seem to have diffused. In the process of writing this paper, the head of the R&D department was contacted. While the substantive content of the story was verified, the author was asked not to disclose the name of the company. According to the R&D manager, analyses of competitors' designs show that the theoretical insights reached over a decade ago have not yet diffused. Hence, the company is anxious not to reveal the potential discovered in its scientific approach.

[13] The *ceteris paribus* assumption is necessary in view of the fact that both imitation and replication are influenced by a range of other factors than the degree of articulation of the knowledge in question (von Hippel 1994). In fact, the relative empirical importance of tacitness as opposed to these other factors has yet to be demonstrated. In view of the central role attached to knowledge characteristics in much current theorizing, such demonstration seems to be urgently needed. There is an apparent danger that – as in the case of the Schumpeterian hypotheses regarding the influence of firm size and concentration on innovation (Cohen and Levin 1992) – too much attention will be devoted to an issue of consequence for academic theory but detached from the empirical reality to which it is meant to apply.

[14] Following Hayami & Ruttan (1971), three stages of technology transfer can be defined. *Materials transfer* refers to the capability to use a new product. The technology transferred is articulated in an artifact. In the simplest case, the use of the artifact is self-explanatory, requiring no or only limited prior knowledge on part of the receiver.

The second stage, *design transfer*, involves the capability to manufacture the product. This requires not only the transfer of blueprints and other coded information but also the ability on part of the recipient to interpret the code. The more complete this documentation, i.e. the higher the degree of articulation and codification of the requisite knowledge, the more feasible is the use of inexpensive impersonal means to execute the transfer. However, unless the recipient is familiar with the code, more or less expensive training programs may still be necessary.

The third phase, *capacity transfer*, refers to the ability to further develop the technology. In addition to mastery of the appropriate codes, the absorptive capacity of the target organization must also include relevant cognitive elements, i.e. theoretical knowledge, as well as the capacity for innovation. Whereas codes and theory are, at least in principle, articulable, innovatory capacity includes creative skills that are largely tacit.

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