The Dynamic Relationship Between Tacit and Codified Knowledge: Comments on Ikujiro Nonaka's, "Managing Innovation as an Organizational Knowledge Creation Process"

by

Paul S. Adler
Department of Management and Organization
School of Business Administration
University of Southern California
Los Angeles, CA 90089-1421

Published in G. Pogorel and J. Allouche (eds.) **International Handbook of Technology Management**, Amsterdam: North-Holland, 1996.

Acknowledgements:
Research assistance by Mark Zbaracki is gratefully acknowledged, as is funding support from the Stanford Institute for Integrated Manufacturing.

The Dynamic Relationship Between Tacit and Codified Knowledge: Comments on Ikujiro Nonaka's, "Managing Innovation as an Organizational Knowledge Creation Process"

Recent research in several apparently unrelated fields has highlighted the insights afforded by distinguishing between two forms of knowledge: explicit knowledge — in its most elaborated form, science — and tacit knowledge — in its most elaborated form, art. Explicit knowledge consists of facts, theories and principles that are codified in research journals, taught in schools, and recorded in industry. In contrast, tacit knowledge is personal and cannot easily be communicated. In industry, tacit knowledge is particularly valued in the skill of a craft worker and the design know-how of an engineer — in general, the accumulated tricks of the trade.

This research suffers, however, from an important limitation, a limitation inherited perhaps from Michael Polanyi's (1958, 1966) original treatment of the issue: it has relied on an exclusively static contrast between tacit and explicit knowledge. In reality, the relationship between tacit and explicit knowledge is not static. For example, while many traditional manufacturing operations rely on extensive bodies of tacit "art" such as found in the skills of craft workers, these skills are often the object of intensive codification efforts. The skill is first made explicit as a set of heuristics and then, through further analysis, "reduced to science."

In the chapter under discussion, Ikujiro Nonaka has developed a conceptual framework that categorizes this type of knowledge creation — he calls it "externalization," but "codification" might be a more intuitive term — as one of four types of knowledge creation: externalization, internalization, socialization, and combination. In doing so, he has opened the way to more fruitful research on a crucial issue that reaches into the heart of the process of technological innovation. His chapter goes on to use this framework to inform a rich analysis of the innovation process and its key management challenges; but my comments will focus on this starting point.

Before exploring the internal logic of this framework, it should be noted that the tacit/explicit distinction is only one of several dimensions along which forms of knowledge can be characterized. Nonaka mentions several other dimensions in a footnote: universal/specific, public/private, degree of observability, complexity, interdependence. It is not at all obvious at the outset that the tacit/explicit distinction is the one that will provide the most fruitful overarching structure for a theory of the knowledge creation process. While the richness of Nonaka's chapter makes an effective case for such a focus, future research should assess the possible contributions of these other dimensions to our understanding.

Turning now to Nonaka's typology itself, we should note that three of the four cells have been studied by researchers in other fields, and future technology management research could benefit from this knowledge base. First, educational researchers have studied how students "internalize" codified textbook knowledge: we are starting to understand the importance of "active" learning, and in particular to understand the key role played by the mobilization of prior knowledge in facilitating or impeding this internalization. Learners are not "empty vessels" into which knowledge is poured. For the effective learning of explicit forms of knowledge, learners must have the opportunity to link the new knowledge to their existing knowledge and its underlying assumptions, and for this to occur, practical use of the new knowledge in natural settings is critical.

Second, sociologists and anthropologists have studied the transmission of tacit knowledge in the acculturation process; this provides a powerful model for the "socialization" process such as we observe it at work in situations such as apprenticeship. Notwithstanding Nonaka's (playful?) comment on U.S. MBA education as a (mere?) combination of existing bodies of explicit knowledge into new explicit knowledge, the more forward-thinking business schools have sought to develop pedagogical methods that address the need for the trasmission of managers' tacit knowledge: this is the logic of the famous Harvard Business School case-study approach to learning the "art" (as distinct from the science) of management.

Third, historians of science have studied the “combination” process, the elaboration of explicit knowledge into further explicit knowledge. But here we encounter an important limitation of Nonaka’s framework. As Nonaka himself points out, the effective pursuit of “combination” typically requires an important dose of tacit knowledge, in particular in the form of metaphor and insight. This dependence of combination on tacit knowledge highlights a key limitation of Nonaka’s 2x2 matrix: the distinction of tacit and explicit forms of knowledge is important for classifying knowledge at a given point in time, but it may not be so helpful in characterizing the development of knowledge over time.

The fourth cell, “externalization,” in contrast with the other three, refers to a process about which we currently know little (or at least about which little has been externalized!). The benefits of such externalization/codification may be enormous. First, a process that once depended upon the experience of a particular worker can be more easily taught to new workers. Second, codification permits standardization, and a standardized practice is more amenable to improvement. Third, the passage from tacit to codified is a process that seems to gain momentum: each new step in codification strengthens the foundation for further investigation.

But here again we encounter the previously-mentioned limitation of Nonaka’s framework when we ask: what is the role of tacit knowledge in the newly codified field? Most of those who have explored the real functioning of codified bodies of knowledge agree that tacit knowledge does not simply disappear — the codified knowledge, to be useful, must be “internalized,” to use Nonaka’s term — but no clear model of the dynamic relationship between tacit and explicit knowledge has emerged. The goal of my comments is therefore to use Nonaka’s framework as a stepping stone toward the elaboration of such a dynamic model.

My comments are in two parts. The first part briefly reviews previous research in several fields that has used the tacit/explicit distinction, beginning with an outline of Polanyi’s notion of tacit knowledge and then examining the deployment of that notion in various fields. The second part focuses on the problem of a the dynamic interrelationship of tacit and explicit knowledge, in particular as it occurs in the process of externalization/codification.

PREVIOUS RESEARCH ON TACIT KNOWLEDGE

Michael Polanyi

Michael Polanyi (1958, 1966) developed the notion of tacit knowledge in response to the doctrine of scientific objectivism which he traced to the work of Locke and Hume. Objectivism claims that scientific theory must be testable by experience. Theory contradicted by experience must either be revised or rejected. Further, theory that does not relate to experience or cannot be tested should also be revised, so that it can be compared to experience. This doctrine leaves no place for personal judgement — all relevant knowledge is, by definition, objective rather than personal.

Polanyi considered this view inadequate because he thought science always retains a personal element. Tacit knowledge — the fact that "we know more than we can tell" — is that personal element. Around this idea Polanyi built his system of philosophy.

Polanyi demonstrates the importance and generality of tacit knowledge through an analysis of perception. At one level, the level of "focal awareness," is the object to which we attend. At another level, the level of "subsidiary awareness," are the particulars of that object. In attending to the focal awareness, we can identify the object, but we cannot identify the particulars of our subsidiary awareness — they are tacitly known. For example, in recognizing a face, we are only aware of the face as a whole. Though we use the features of the face to identify the person, we cannot simultaneously attend to the specific features of the face and to the face itself. Focusing on the particulars destroys the meaning of the object of our focal awareness. We tacitly know the particular features through our subsidiary awareness of them while attending to the face as a whole.

The tacit/explicit distinction helps explain not only psychological "primitives" such as perception, but also higher-order operations, such as skilled performances such as dancing and cognitive functions such as scientific research. In the realm of the skilful performance, tacit knowledge manifests itself in the routine of the performance. The performer cannot attend to the elements of the performance, for then the performance would fall apart. A skillful performance requires the performer to focus on the whole, and be aware of the particulars of the performance only subsidiarily.

Tacit knowledge also operates in science, and this in at least three different ways. First, identifying a research question — a problem for explanation — requires tacit knowledge. Identification of a "good" problem must occur through tacitly knowing that something worth discovering is near.

Second, tacit knowledge is required to make sense of scientific theory. In order to use a theory, we must engage in an act of "indwelling," or in Nonaka's terminology, internalization — understanding the joint meaning of the theory and the facts to which it refers requires an intuitive understanding of the linkage between the theory and the facts. Thus, understanding the results of an experiment cannot involve a simple empirical confirmation or denial of a theorem; interpreting the results demands a deeper understanding, using tacit knowledge.

Finally, tacit knowledge aids the scientist in understanding when and how to deploy formal methods. Science demands intuition, not only methodical testing of theory. Polanyi describes how the scientist might encounter results that seem to disconfirm a theory but nevertheless not reject the theory. Instead, the scientist looks for the possibility of error in the method, checks the data over, and, if the results still hold, may simply reject the results as unreasonable, because of some inexplicable confidence in the theory — some tacit knowledge, affirming the theory over the objective results. Kuhn's analysis of scientific revolutions can be seen as supporting this view of the practice of science.

Tacit knowledge in organizational research

We hear several echoes of these issues in the field of organizational research:

* Gerwin (1981) summarizes two key dimensions of types of technology as variety and explicitness. This parallels Perrow's distinction between the number of exceptions and the degree of difficulty in solving them. Explicitness in this sense subsumes predictability and controllability.

* March and Simon (1958) analyze the role of routines, whether tacit or codified, in organizations. March and Simon identify routines as an essential component of

organizational life, and notes that they significantly influence behavior of individuals and groups.

* A number of scholars (e.g.: Daft and Lengel, 1986) have explored the way communication media and organizational arrangements vary with the degree of ambiguity and equivocality in the information that needs to be processed. Tacitness is key component of equivocality.

* Much of the literature on organizational culture argues that culture is most effective in shaping behavior when the relevant components of culture are tacit. Schein (1984) for example, argues that culture derives much of its power to shape organizational behavior through the impact of deep-seated assumptions about the way the world works. These assumptions, he argues, are powerful precisely because they are invisible — tacit.

* The research on bureaucracy and formalization in organizations (Hall, 1987) highlights the contrast between "organic" and "mechanistic" structures (Burns and Stalker, 1961) — which is fundamentally a difference in the degree of tacitness of the organizational routines. More generally, the contrast between the formal and informal aspects of organization largely overlaps the distinction between codified and tacit.

Tacit knowledge in the sociology of work

Sociologists have employed the tacit/explicit distinction in the question of technological change and "deskilling." Though the issue finds its roots in the ideas of Karl Marx, the problem is explicitly stated by Harry Braverman (1974). Braverman argued that the objective of production efficiency pushes managers to seek greater control — through eliminating worker autonomy — and lower costs — through reducing skill requirements. "Scientific management," as developed by Frederick Taylor, provides management with key techniques for achieving both goals — time-and-motion studies reduce skill requirements and the conduct of these studies by managers (or by loyal industrial engineers) reduces worker autonomy. Braverman claims workers are thus left with mindless tasks. Braverman sees automation as a further opportunity for management to eliminate the skill in workers' tasks, particularly in such crafts as machining, and to embody it in the automated equipment. The worker, once highly skilled, now merely tends a machine.

Manwaring and Wood (1984), using Polanyi's theory of tacit knowledge, criticize this deskilling proposition. They argue that workers possess tacit skills which management's deskilling efforts cannot remove. They identify three types of tacit skills. First, workers accumulate tacit skills through routine experience — for example, driving, typing, or operating a machine. Even the performance of extremely simple tasks improves with the accumulation of such tacit knowledge. Second, effectively performing repetitive activities typically requires tacit "tricks of the trade." They cite examples where workers must make minor adjustments which the official procedures do not identify, but the worker has learned through experience. Finally, effective task performance usually requires cooperative skills, necessary due to the collective nature of the labor process. Manwaring and Wood argue that although important divergences of interest separate capital and labor, managers need workers' tacit skills. This limits the effectiveness of the Taylorist system.

Tacit knowledge and computer-based system design

A third area of research that has used the tacit/explicit distinction to powerful effect is some of the research on work-oriented or user-oriented computer system design. Ehn's analysis of the design of computer-based systems (Ehn 1988) relies greatly on the tacit/explicit distinction. He argues that "tacit knowledge neither can nor should be formalized into algorithmic procedures" (1988. p. 445). This argument relies on a notion of tacit knowledge drawn from Polanyi as well as Heidegger's analysis of the "ready-at-hand" (1962) and the analysis of game-playing in Wittgenstein's later work, specifically <u>Philosophical Investigations</u> (1953).[1]

Toward the end of his book, he summarizes an interesting discussion by Janik (1986) of three forms of tacit knowledge that can be codified:

1. knowledge that has been kept tacit for political or economic reasons — such as some craft trade secrets.

---

[1] This line of thought owes much to Winograd and Flores (1986) and Dreyfus and Dreyfus (1986).

2. knowledge that could be made explicit but never was because no one had an interest in doing so. For example, much, but not all, the craft skill of the blacksmith, Janik argues, could be made explicit by the kind of analysis proposed by Frederick Taylor. Here Ehn and Janik give Polanyi's analysis an interesting twist: they argue that not all the relevant knowledge could ever be made explicit without deskilling and degrading the worker.

3. knowledge that constitutes the presuppositions of everyday practice, which never comes to mind except in conditions of breakdown. Here Ehn and Janik retain Polanyi's analysis that if too much of this background knowledge becomes explicit, it will impair the performance of the task at hand.

Apart from these three kinds of tacit knowledge — forms that could in principle at least in part be rendered explicit — there is another form of tacit knowledge that remains totally resistant to codification: the tacit knowledge that takes the form of aesthetic and moral judgements. Such knowledge is communicated by experience under the guidance of someone more skillful.[2]

Finally, there is the tacit knowledge that allows the expert to know when the transcend the traditional rules, whether these rules are explicit or tacit. This Ehn and Janik consider the most important element of tacit knowledge, and it too defies codification.

Tacit knowledge and the economics of technological evolution

Conventional economic analysis of knowledge (see for example Arrow, 1962) focuses exclusively on explicit and public knowledge. Economic research on explicit knowledge assumes that knowledge can be transferred without cost by simple duplication.

But much important technological knowledge is tacit. To the extent that the knowledge is tacit, it cannot be costlessly duplicated. Indeed, it may not be transferable at all without transferring the people who possess the knowledge. Growth of tacit knowledge depends less on traditional factors of technological

[2] Ehn 's discussion here is rather confused, since he attempts to ground the difficulty of articulating this knowledge in the sensuous nature of the experience that gives rise to the knowledge. But moral judgements, unlike aesthetic ones, don't necessarily or even typically have a sensuous base, and some elements of aesthetic understanding can indeed be rendered explicit, and this category of knowledge therefore belongs to Janik's type 2.

progress, such as publications and patents, and more on firm-specific efforts and the cumulative learning that ensues.

Dosi (1982, 1988) argues that tacit knowledge is a key element of the innovative process. First, he develops the concept of "technological paradigms." Following Kuhn (1970), Dosi defines a technological paradigm as a "'model' and a 'pattern' of solution of <u>selected</u> principles derived from natural sciences and on <u>selected</u> material technologies" (1982, p. 152, emphasis in original). Dosi argues that the direction of the technological change follows a "technological trajectory," which is the "pattern of 'normal' problem solving activity." Technological knowledge is not as well codified as scientific knowledge. Kuhn's analysis of scientific revolutions shows the importance of tacit knowledge in shaping the trajectory of scientific knowledge, and tacit knowledge shapes technological development even more powerfully. The paths of technological growth do not simply reflect market demands or scientific developments.

Teece (1988) echoes these themes in his work on technology transfer. He sees the tacit/explicit distinction as central to the choice of technology transfer mechanisms. First, the presence of tacit knowledge adds to transaction costs. Second, where tacitness makes transfer of knowledge is difficult, "first mover" advantages may be greater. Finally, tacit knowledge tends to be cumulative, because knowledge from one project carries over to the next. Therefore, in the presence of tacit knowledge, non-market transfer mechanisms — vertical integration of production and research and development — should dominate over external contracting.

In their analysis of economic growth, Nelson and Winter (1982) also use Polanyi's notion of tacit knowledge, both explicitly and implicitly. They argue that orthodox economic theory does not deal well with the dynamics of change because this theory obscures essential features of the firm. Orthodox economic theory assumes that firms maximize profit by selecting from a comprehensive and codified set of technological alternatives ("recipes") the optimal technique. Nelson and Winter's evolutionary model follows March and Simon, assuming instead that firms have a relatively fixed way of doing things, a set of routines which are difficult to change. These routines are organizational-level analogues of Polanyian tacit skills. When environmental conditions change, firms face a tradeoff: if, in response to a changed context, they attempt to change their routines they will perform less efficiently, albeit more "effectively" — the ubiquitous tension between "doing the thing right" and "doing the right thing."

While firms' reliance on routines is not irrational, it indicates that they do not optimize in the conventional sense of the term. The orthodox economic optimization model ignores this key feature of organizational reality. When conditions worsen sufficiently, firms search for new routines, evaluating their current routines, and possibly modifying or replacing the established routines. The selection environment — market conditions and characteristics of other firms in the industry — determines whether firms practicing particular routines will grow or contract.

THE IMPORTANCE OF DYNAMICS

The tacit/explicit distinction contributes in important ways to our understanding of several important phenomena, but one cannot but be struck by the almost total absence of discussion of the dynamic issue: how does tacit knowledge become explicit and codified? What is the new role of tacit knowledge once the old tacit knowledge has been codified?

Polanyi himself was fully pre-occupied by the task of demonstrating the ubiquity of tacit knowledge. It is only in occasional asides that he allows that explicit forms of knowledge offer some important advantages.[3]

This dynamic process of codification is not well apprehended in any of the bodies of research we have just reviewed:

• With respect to the role of tacit knowledge in organizational theory, we wonder about questions such as these: How do organizations transform tacit into explicit technologies? Does it make a difference to March's analysis whether routines are tacit or explicit? What happens when routines are made more explicit? Organizational research has often contrasted organizations with high and low degrees of formalization, but how should we understand the process of formalization? This is essentially a process of codifying tacit procedural know-how;

---

[3] In Personal Knowlege, a chapter on "Articulation" discusses only the parallelism between the tacit and more explicit forms of knowledge in the way both are progressively elaborated, and articulation turns out to have little to do with the passage from tacit to explicit.

how does this process unfold? Cultural change is sometimes deliberately organized, and in this process, making implicit assumptions explicit can play a key role; how does this happen and what is the subsequent impact on culture?[4]

• Manwaring and Wood do not address the significance of a Tayloristic effort to codify tacit skills. They show that there is always at least a residue of tacit knowledge required to effectively deploy a machine or an explicit routine, but this hardly seems like a fundamental criticism of Braverman's thesis that overall skill requirements are progressively reduced. A more important criticism of Braverman is that he was simply wrong in his basic thesis: in reality, technological change under capitalist conditions leads more often than not to higher skill requirements (Adler, 1986, 1987). But these higher skills are often more technical and less craft-like: thus a series of questions about new forms of off- and on-the-job training required for the new workforce.

• Ehn recognizes that computer designers often completely transform the way work is done; he therefore addresses at least part of the dynamic issue we are studying. He conceives of this transformation of work processes as operating in one of two possible ways. Either tacit knowledge is codified, as in Janik's second form, in which case he argues that deskilling and degradation will inevitably result. Or the current configuration of tacit and explicit knowledge undergoes a "transcendence" — the expert knows when to break with established tacit understandings and attempt to create a whole new fabric of understanding. From Ehn's Polanyian perspective, however, such transcendence can only be understood as a untheorizable leap, since codification is equated with degradation. Sometimes change may indeed take this somewhat mysterious form; but it often occurs through a less mysterious leap of creativity, through a sustained painstaking codification effort — a process into which Ehn's approach offers no insight.

• Dosi's discussion of technological trajectories appears compelling, but begs for discussion of the trajectory that might take a body of tacit knowledge to the form of codified science. What influence would such a transformation have on the dynamic of development? [5]

---

[4] Swidler (//) discusses the role of more explicit elements of culture in the process of societal change.

[5] Note a prior problem in Dosi's account: it is not at all obvious that it is the tacitness of technology that accounts for trajectories. It is equally plausible that the trajectory form of technological development flows from the uneven texture of the space of technological opportunities.

• Teece's analysis of technology transfer seems clearly superior to accounts that fail to consider the transaction costs of transferring tacit knowledge. But his analysis remains a static comparison. In practice, the choice of transfer mechanisms might also be influenced by the likelihood that, within the relevant time horizon, tacit know-how would be transformed into explicit recipes.[6]

• Finally, Nelson and Winter's analysis highlights the tacit routines that characterize organizational life. This leads to a more realistic model of economic growth. But what happens when these routines are made explicit? The more explicit statement of routines both reduces the dependence on individual actors and, presumably, improves the probability of successful implementation of new routines.

THE DYNAMIC RELATIONSHIP OF TACIT AND EXPLICIT KNOWLEDGE: AN HYPOTHESIS

In this section, I will first briefly sketch one case of externalization that I have studied in manufacturing, that of the codification of "design for manufacturability" knowhow. I then use this example to sketch a conceptual model of the dynamic interrelationship of tacit and explicit knowledge.

DFM know-how: a case study of the transition from art to science

A growing number of U.S. manufacturing companies are placing greater emphasis on ensuring an optimal fit between product design parameters and manufacturing process parameters — a fit that is commonly referred to as Design for Manufacturability (DFM). Better DFM fit ensures lower manufacturing cost, higher manufacturing quality, and faster manufacturing ramp-up.

A key mechanism for achieving DFM is the involvement of manufacturing engineers earlier in the product development cycle. But when manufacturing is invited to participate earlier in the design process, we sometimes find that they feel

---

[6] Note too, that both Dosi and Teece treat tacit and explicit knowledge as separate realms of knowledge. Thus, they see explicit knowledge as something that one organization can costlessly gain from another, but tacit knowledge as more firm specific. However, Polanyi saw tacit knowledge as integrally related to explicit knowledge; even explicit knowledge has a corresponding tacit element. Explicit knowledge is useless without a corresponding tacit understanding (c.f. Nonaka's internalization, Polanyi's indwelling). Teece oversimplifies even the comparative-statics problem.

that their knowledge of the manufacturing department's process capabilities is insufficient. In part, this is because much of that knowledge is in tacit form — it is experience-based know-how. To the extent that their knowledge of manufacturability is only tacit, manufacturing engineers have a hard time explaining their "feeling" that this design will work but that one won't. As organizations develop greater trust between product designers and manufacturing engineers, some of the tension around the value of such feelings is often defused — since after all, these intuitive assessments are often the fruit of many years of experience — but the tacit form creates certain insuperable barriers to the refinement of DFM knowledge.

Two limitations are obvious:

• First, when this knowledge is in tacit form, manufacturing engineers can only respond to proposed designs — they find it difficult to articulate the envelope of manufacturing potential. The use of joint design teams is one way to facilitate access to manufacturability knowledge even when it is in tacit form. Making that knowledge more explicit as a set of producibility guidelines can enable design engineers to eliminate many of the simpler manufacturability problems, and can thus economize on design iterations and design team meetings.

• Second, when manufacturing knowledge is in tacit form, it is very difficult to pursue a program of deliberate refinement and testing.

We therefore find many DFM-conscious organizations devoting considerable resources to the objective of shifting the form of their manufacturability knowledge-base from the tacit to the science end of the spectrum. I discuss some elements of this codification effort in Adler (1992).

But I have also found that some managers and engineers assume that such a shift from tacit knowledge to science, if pursued far enough, could eliminate reliance on any element of tacit knowledge. Anecdotal evidence from my fieldwork as well as the experience of other codification efforts suggest that this assumption is most likely mistaken. First, not all the manufacturability knowledge will ever be captured in the producibility design rules. Second, even if both product and process design were fully scientific, the intelligent use of that scientific knowledge calls on judgement based on tacit knowledge. Third, as manufacturing evolves, tacit knowledge will be needed to know how to update and extend the design rules.

So we would expect organizations with world-class DFM to (a) maintain their use of product/process teams and/or (b) ensure that their product designers had enough exposure to manufacturing to give them the contextual knowledge needed to know when to rely on and when to override the producibility guidelines.

A model of the dynamic relationship between tacit and explicit knowledge

We can use this case of DFM codification to develop a conceptual model of the change from tacit to explicit knowledge, and of the role of tacit knowledge in that process. Initially, at T_0, knowledge in the given field presents itself as entirely tacit. Through a process of investigation and documentation, this knowledge becomes more explicit. Nonaka has elsewhere (1991) characterized this process as a progression from metaphors to analogies to models, but it is not yet clear whether this proposition is generalizable. Whatever the process, the knowledge field at T_1 now contains both explicit, codified forms of previously tacit knowledge and some residue of the old tacit knowledge that remains in tacit form. But now some new elements of tacit knowledge are needed to make sense of the newly explicated knowledge. Here, Polanyi's analysis seems plausible. Moreover, a third category of tacit knowledge would seem necessary — the tacit knowledge required to identify new opportunities for further codification. Here, too, Polanyi's analysis of the role of intuition in scientific discovery applies.

As knowledge progresses further, from codified heuristics (T_1) to rigorous science (T_2), a further series of changes seems likely. First, all three of the preceding categories of tacit knowledge persist, but their content will change somewhat. Second, the codified heuristics might be expected to undergo a similar transformation as tacit knowledge did in the first phase: some explicit heuristics remain in that form, as a residual; some new heuristics are developed to assist the deployment of the new scientific knowledge, and some new heuristics might emerge to guide the development of new science.

This externalization scenario — the synthesis of codified knowledge from tacit knowledge — represents the formation of science “from below” as it were. But Nonaka’s analysis reminds us that there is a second scenario we must also consider

— combination, which represents “revolution from above”: here explicit scientific knowledge comes not from the formalization of currently tacit knowledge or from heuristics but from “elsewhere,” from a relatively autonomous realm of science. Here, new explicit heuristics and new bodies of supporting tacit knowledge emerge as part of the “combination” process, in response to the recognition (a tacit function!) of the applications of an existing body of scientific knowledge.

Exhibit 1 summarizes this conceptual model.

[PUT EXHIBIT 1 ABOUT HERE]

These two scenarios can be read as stylized versions of the long-standing debate of the relationship between science and technology (see Layton, 1971, 1974, 1976, 1979). If technology is construed as composed primarily of knowhow and heuristics, then the second scenario is the classic scenario in which technology is “merely” the application of science. Tacit knowledge is vital in this scenario, but only in enabling the recognition of science’s applicability and in guiding the effective deployment of the new knowledge.

CONCLUSION

These comments have focused on some of the conceptual underpinnings of Nonaka’s essay rather than his model of the innovation process itself. But the distinction between tacit and explicit knowledge is a crucial one both for Nonaka’s model and for a broad range of research efforts. Moreover, the question of the dynamic interaction between these two forms of knowledge is at the very heart of the process of technology management. Future research will hopefully further elucidate this interaction.

REFERENCES

Adler. P. S., 1992, “Organizational Learning: The Case of Manufacturability Assurance in the Product Development Process,” IBEAR Research Conference on Comparative Strategies for Change in the U.S. and Japan, University of Southern California, May 10-12.

Adler, P.S., 1986, “New Technologies, New Skills.” California Management Review, Fall, pp. 9-28.

Adler, P.S., 1987, “Automation and Skill: New Directions.” International Journal of Technology Management, 2, 5-6, pp. 761-772.

Arrow, K., 1962, “Economic Welfare and the Allocation of Resources for Invention,” in National Bureau of Economic Research, The Rate and Direction of Inventive Activity, Princeton, NJ: Princeton University Press.

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

Burns, T. and G.M. Stalker, 1961, The Management of Innovation, London: Tavistock.

Daft, R. L., and R. H. Lengel, 1986, “Organizational Information Requirements, Media Richness, and Structural Design,” Management Science, 32, pp. 554-71.

Dosi, G., 1982, "Technological paradigms and technological trajectories: A suggested interpretation of the determinants and directions of technical change," Research Policy 11(1982) pp. 147 - 162, North Holland Publishing Company.

Dosi, G., 1988, "The nature of the innovative process," in Giovanni Dosi, Christopher Freeman, Richard Nelson, Gerald Silverberg, and Luc Soeter, eds., Technical Change and Economic Theory, London: Pinter, pp. 221-238.

Dreyfus, H.L. and Dreyfus, S.D., 1986, Mind over Machine, Glasgow: Basil Blackwell.

Ehn, P. 1988, Work-Oriented Design of Computer Artifacts, Stockholm: Arbetslivscentrum.

Gelwick, R., 1977, The Way of Discovery: An Introduction to the Thought of Michael Polanyi, New York: Oxford University Press.

Gerwin, D., 1981, “Relationships between structure and technology,” in Paul C. Nystrom and William H. Starbuck, Handbook of Organizational Design, New York: Oxford U.P.

Hall, R. H., 1987, Organizations: Structures, Processes and Outcomes, Englewood Cliffs, N.J.: Prentice Hall.

Heidegger, M., 1962, Being and Time, New York: Harper and Row.

Janik, A. 1986, Tacit Knowledge, Working Life and Scientific Method, Brenner Archive, Innsbruck University.

Kuhn, T. S., 1963, in A. Crombie, ed., Scientific Change, New York: Basic Books.

Kuhn, T. S., 1970, The Structure of Scientific Revolutions, 2nd ed., Chicago: University of Chicago Press.

Layton, E. T., 1971, "Mirror Image Twins: The Communities of Science and Technology in 19th Century America," Technology and Culture, 12:4 (October 1971) pp. 562-580.

Layton, E. T., 1974, "Technology as knowledge,: Technology and Culture, 15:1 (January 1974) pp. 31 - 41.

Layton, E. T., 1976, "American Ideologies of Science and Engineering," Technology and Culture 17:4 (October 1976) pp. 688-701.

Layton, E. T., 1979, "Scientific Technology, 1845-1900: The Hydraulic Turbine and the Origins of American Industrial Research," Technology and Culture, 20:1 (January 1979), pp. 64-89.

Manwaring, T. and S. Wood, 1984, "The Ghost in the Machine: Tacit Skills in the Labor Process,: Socialist Review, Number 74, Volume 14:2 (March-April 1984).

March, J. G. and H.A. Simon, 1958, Organizations, New York: Wiley.

Nelson, R. R., and S. G. Winter, 1982, An Evolutionary Theory of Economic Change, Cambridge: Harvard University Press.

Nonaka, I., 1991, "The Knowledge Creating Company," Harvard Business Review, November-December, pp. 96-104.

Polanyi, M., 1958, Personal Knowledge: Towards a Post Critical Philosophy, Chicago: University of Chicago Press.

Polanyi, M., 1966, The Tacit Dimension, Garden City, N.Y.: Doubleday Anchor.

Schein, E. H., 1984, "Coming to a New Awareness of Organizational Culture," Sloan Management Review, Winter, pp. 3-15.

Teece, D. J., 1988, "Technological change and the nature of the firm," in G. Dosi, et al., eds., op. cit.

Winograd, T. and F. Flores, 1986, Understanding Computers and Cognition, Norwood: Ablex.

Wittgenstein, L, 1953, Philosophical Investigations, Oxford: Basil Blackwell.

Exhibit 1
A MODEL OF THE GROWTH OF KNOWLEDGE