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KNOWLEDGE INTEGRATION IN LARGE-SCALE ORGANIZATIONS AND NETWORKS – CONCEPTUAL OVERVIEW AND OPERATIONAL DEFINITION

by

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Abstract

Knowledge integration is an emerging discipline in organizational science where the central proposition is that the increasing complexity of products and services being developed and delivered, means that the knowledge required for production is increasingly specialized, varied (multi-disciplinary) and distributed across the organization's internal boundaries, and as a result there is a need for organizations to continuously gather their knowledge resources in order to maintain their ability to innovate, and to sustain their competitive position in the market. In addition, the increasing scale and scope of organizational arrangements, such as multinational partnerships or multi-tiered prime-supplier arrangements commonly encountered in the aerospace, automotive and other complex product development industries, also give rise to environments of dispersed knowledge resources, thus necessitating the subsequent integration of this knowledge across external boundaries spanning large-scale organizational networks. Knowledge integration in this context is done through a process of *transferring* knowledge from multiple sources in the organizational network to where it is needed, *combining* it with existing knowledge, before it can be *applied* to accomplish complex tasks and to solve major problems.

The primary purpose of this paper is to define the powerful concept of knowledge integration in large-scale organizational networks using an extensive review of the pertinent literature on knowledge in organizations. An operational definition for knowledge integration is also proposed, followed by a systematic identification and classification of the different strategies, practices, channels and mechanisms for integrating different types of knowledge across a multitude of organizational boundaries and environments.

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Introduction

The need for integrating diverse knowledge from multiple sources across organizational boundaries is a real world problem of great strategic significance for any organization. This is because knowledge is widely considered as a strategic differentiator between firms (Nonaka 1994; Grant and Baden-Fuller 1995; Conner and Prahalad 1996) and essential for creating and sustaining competitive advantage (March 1991; Nonaka and Takeuchi 1995; Prusak 1996). This is especially true for large-scale organizations and organizational networks since knowledge resources are widely dispersed in this context. The organization's primary concern then becomes one of integrating (sometimes the term "combining" is used) all of its distributed knowledge resources in order to apply them in production (Grant 1996a). However, the knowledge integration phenomenon is currently poorly understood both in the literature and in practice, first in terms of the lack of clarity and consensus over what constitutes knowledge integration versus other forms of knowledge manipulation such as transfer, sharing, coordination and other concepts commonly encountered in the literature (Grant 1996b; Okhuysen and Eisenhardt 2002); and second, in terms of the lack of guidance for how the integration process is actually carried out in practice in an efficient and effective manner (De Boer, Van Den Bosch et al. 1999; Hansen, Nohria et al. 1999).

It is therefore valuable from both the theoretical and practical perspectives to provide a clear definition for the knowledge integration phenomenon at both the conceptual and operational levels. To this end, we will start with an extensive review of the literature addressing the different types and characteristics of knowledge in organizations (Nonaka 1994; Von Hippel 1994), as well as the theory behind knowledge transfer (Aoshima 2002; Carlile 2004), knowledge sharing (Dyer and Nobeoka 2000; Hansen 2002), organizational learning (Senge 1994; Argote 1999) and boundary spanning (Star 1989; Carlile 2002), all of which are major constituents of the knowledge integration process. But before addressing what constitutes knowledge integration, we will start by providing an overview of what is meant by the term "knowledge" in the organizational context.

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Defining "Knowledge" in Knowledge Integration

Much has been written in economics and organization theory about the related concepts of knowledge and information, starting with the pioneering views of the economist Alfred Marshall who was the first to advocate that "*knowledge is the most powerful engine of production*", and who advanced a positivist view of knowledge as an objective and fixed asset belonging to the organization, such as the information captured in rules, procedures and work practices. In this view, the organization was seen as a repository of information, with the main focus being on the efficient utilization of this information in order to achieve competitive advantage. This view remained dominant in the literature through much of the early period of the information age from Frederick Taylor to Herbert Simon, who further advanced that the organization can be considered as an information-processing entity where individuals represent the weakest link due to their "bounded rationality", a concept that Simon developed to describe the cognitive limitation on the ability of individuals to process information (Simon 1973). This meant that the design of authority and decision-making structures in the organization had to minimize information overload on the individual. As a result, and in order to make up for this human limitation, organizations had to increase their collective capacity for processing information through machines and infrastructure (Simon 1973; Galbraith 1974).

In contrast to the early objectification of knowledge, later works by Friedrich Von Hayek and Michael Polanyi defined the powerful concept of tacit (or implicit) knowledge held by individuals, also known as subjective knowledge, and that is evolved through personal experience (Polanyi 1966). In this subjective view, knowledge is the property of the individual instead of the organization, it is superior to data and information found in books and repositories, and its maximization comes through individual learning and experience (learning-by-doing) rather than by organizational processes only. Yet despite this important contribution in highlighting the role of the individual's knowledge in the organization, the earlier objective view of knowledge continued to dominate thinking and practice for much of the 20th century, with the Simonian thinking being the cornerstone of the modern revolution in information technology where organizations turned their attention almost exclusively to the implementation of information systems for moving and managing data and information quickly and cheaply. But

the overemphasis on information processing in organizations over the past few decades came at the expense of developing and retaining the more dynamic and valuable tacit knowledge of individuals, and it wasn't until recent success stories from the Japanese tradition in knowledge management (as demonstrated by the success of the Japanese manufacturing industry), that attention in practice turned again to the subjective view of knowledge (Womack, Jones et al. 1991; Nonaka and Takeuchi 1995; Womack and Jones 1996). This was later followed by more recent attempts at developing a new knowledge-based theory of the firm rooted in the subjective view of knowledge (Demsetz 1988; Kogut and Zander 1992; Foss 1993; Spender 1996; Grant 1996a).

The ensuing reaction against the information-centric view of knowledge generated a host of perspectives still common today that completely separate knowledge from information and data. In this reactionary view, the use of the term "knowledge" is short for describing personal tacit knowledge exclusively, namely to the exclusion of objective information and data. The practical driver behind this differentiation was the recent realization of the significant value of individual tacit knowledge in production, something that was previously ignored by organizations in favor of superior information processing capabilities. The theoretical underpinning of this view is the reasoning that knowledge is exclusive to the individuals who create it and develop it out of their own personal experiences, making it a very personal asset (Nonaka 1994). Knowledge is thus considered synonymous with the subjective beliefs and values of each individual (or group of individuals), and as such cannot be confused or lumped with objective facts and observations. In that sense, knowledge and personal knowledge become one and the same, while objective information and data are seen as separate from personal knowledge and held separately in books and organizational repositories.

While the above appears to be a largely semantic differentiation, it is nonetheless important to note it here since it bears direct consequence on what constitutes knowledge in the organization, and therefore what ultimately constitutes knowledge integration which is the central concern of this paper. Specifically, the limited focus on tacit knowledge under the previous definition downplays the importance of information and data in production, and ignores their role in various knowledge processes in the organization. This not only contradicts reality in everyday

practice, but is also incompatible with widely accepted theory about knowledge creation and learning in organizations where knowledge is considered both tacit and explicit (Nonaka and Takeuchi 1995). In this modern view, both subjective beliefs and objective information are seen as essential components of knowledge[1] which complement each other in a closed-loop cycle of knowledge creation, such that explicit knowledge is the result of articulating tacit knowledge and codifying it into generic information, whereas tacit knowledge is evolved by internalizing information to learn and develop new skills. Similarly in recent perspectives on knowledge integration, knowledge is described as inclusive of information, technology, know-how and skills (Grant 1996a). Here information refers to the codified part of knowledge that is already captured in documents or electronic format; know-how refers to the tacit or subjective knowledge of individuals that is developed through experience and which can be embodied or embedded in technologies, products and tools; and skill refers to the innate personal knowledge of individuals evolved through practice and learning-by-doing. This last definition does not separate information from knowledge, but it does not lump or confuse the two concepts together either.

Given the overview of the theory presented above, the practical question posed at the outset of this section remains: *What is knowledge in knowledge integration?* The historical debate clearly suggests that the inclusive knowledge definition is more useful from the perspective of knowledge integration as it does not exclude the objective part of knowledge from the integration process, while at the same time keeping a distinction with the subjective form of knowledge. Therefore, there is more value in adopting the more inclusive view of knowledge since it leads to a more comprehensive definition of the knowledge integration process. This is in contrast to the exclusivist view which would lead to the exclusion of information and data from the integration process. Specifically, in this paper we use the term knowledge to refer to both the objective part (raw data and information) held by the organization, and the subjective part (know-how and skills) held by individuals, and we adopt the established view that different types of knowledge are not created equal in that there is a knowledge hierarchy where the subjective knowledge of

[1] (Machlup, 1978) defines information as a constituent part of knowledge while making a distinction between the two concepts – information is described as a flow of messages which might add to, restructure or change knowledge that is anchored on the commitment and beliefs of its holders. (Nonaka, 1994) elaborates on this definition to describe the knowledge creation process as the interplay between tacit knowledge and explicit information.

individuals is the most valuable for competitive advantage. This hierarchy is illustrated in the "knowledge pyramid" shown in Figure 1 below.

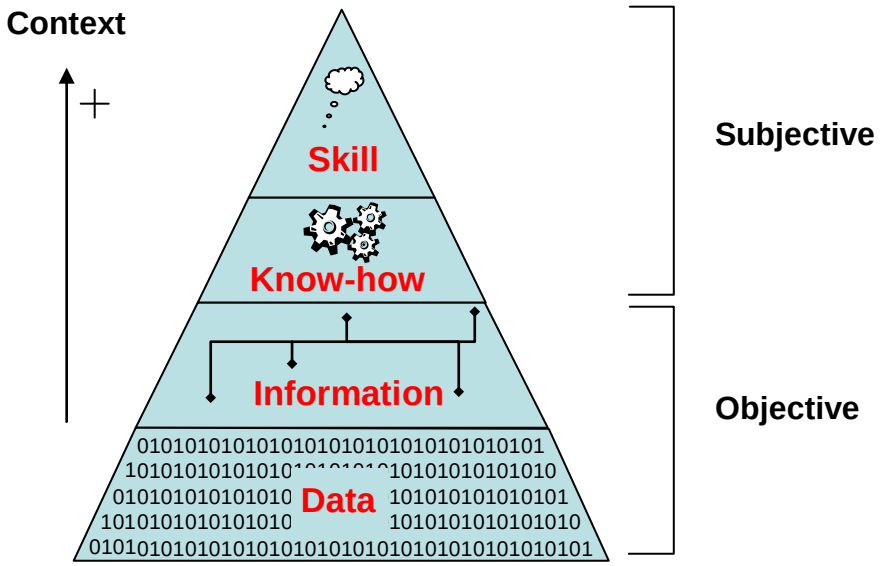

Figure 1: The Knowledge Pyramid

As the above figure illustrates, the hierarchy in the composition of knowledge is based on subjective context, with personal knowledge (or tacit knowledge) being the most contextual and specialized, while impersonal knowledge (or explicit knowledge) is generic and more abstract. Each level of the pyramid builds on the previous level through added context, with raw data (such as the output of a testing process) as the least contextual form of knowledge, followed by information which is made up of raw data that has been processed and put into some context[2] (such as charts and tables that establish relationships between the data), yielding structured or unstructured observations and facts; know-how is then information supplemented with analysis and interpretation or deduction (and can be embodied in physical technologies or products); and finally skill is know-how supplemented with further experience and innate abilities. The process of contextualizing generic data into highly specialized skill is illustrated in Figure 2.

[2] Note that explicit knowledge is not only created from the bottom up by adding context to raw data and information as defined here, but also from the top down by abstracting and capturing tacit know-how and personal skills, such as the explicit knowledge found in science or mathematics books which has been generalized to be true in any context. In both cases, explicit and objective knowledge are considered synonymous since they are both abstract and generic.

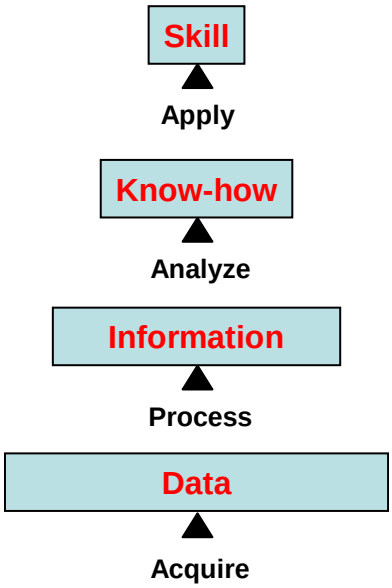

Figure 2: The Build-up of Knowledge

The above figure shows that while knowledge includes information and data, they do not by themselves constitute knowledge in its modern definition. It also shows that individual knowledge takes the most processing and is therefore hardest to build, thus it provides the organization having access to it with competitive advantage. Furthermore, individual knowledge is indeed a higher level of knowledge as shown in Figure 2 since it is the type of knowledge that requires the cognitive processing of individuals. However, it is important to note that in an organizational context, all types of knowledge have their usefulness in solving problems and accomplishing tasks, and are valued differently in different situations.

In summary, this section has introduced the two main types of knowledge that are important for production in organizations, the first is the subjective knowledge of individuals (also referred to as tacit, implicit, or personal knowledge) which takes the form of individual know-how and skills, and the second is objective knowledge (also referred to as explicit, codified or impersonal knowledge) made up of data and information and which is captured in written or electronic format. This paper is concerned with both subjective and objective types of knowledge as the basis for defining knowledge integration. That is, this section has only addressed the question: "What is knowledge?" to clarify what is meant by the term knowledge in the organizational

context in its most general sense (i.e. regardless of what this knowledge is about, whether technical or otherwise). The next section will address the main question of concern in this paper; that is "what is knowledge integration?"

Conceptual Overview of Knowledge Integration

As already discussed, the knowledge-based view in the literature advances the argument that knowledge most relevant for production is created and held by individuals in the course of performing tasks as well as during socialization and reflection (Nonaka and Takeuchi 1995). This means that the organization's knowledge resources are distributed and dispersed across the organization, especially in large-scale multi-program organizational networks where much of the production knowledge resides in the supplier base, outside of traditional firm boundaries (Baldwin and Clark 1997). Therefore organizational performance in the knowledge era is no longer dependent on coordinating tasks and managing information only, but rather on the ability of the focal firm to continuously integrate its dispersed "pockets" of specialized knowledge efficiently and effectively (i.e. in novel and sustainable ways) in order to carry out its production activities and maintain competitive advantage (Kogut and Zander 1992; Purvis, Sambamurthy et al. 2001).

However despite the wide consensus in the literature on the prominence and centrality of knowledge in production activities and the role of the organization as a knowledge integrator, there is still very little theory on what constitutes knowledge integration (Brown and Duguid 2001), and even less on how this integration is accomplished in practice in terms of the actual organizational channels and mechanisms for integrating knowledge (De Boer, Van Den Bosch et al. 1999; Takeishi 2002). Indeed the concept of knowledge integration remains fairly conceptual, meaning that it is still at a fairly high-level of aggregation and lacking a sufficiently detailed common operational definition. In addition, and since the knowledge-based view of the firm is an emerging and relatively nascent thrust in organizational science, it is rife with high-level, vague and often conflicting definitions and interpretations when it comes to the knowledge integration concept. Thus a prerequisite to understanding the mechanics and details of the knowledge integration process is to start with definitions that are more specific and better scoped

than what is currently provided in the extant literature, at both the conceptual and operational levels.

A starting point for a conceptual-operational definition is the one proposed by (Grant 1996a) in which knowledge integration is "a process for coordinating the specialized knowledge of individuals". While this definition clarifies what is involved in knowledge integration (e.g. a coordination process involving the tacit knowledge of individuals), it remains tautological from an operational perspective, in the sense that it describes integration as coordination, which is an equally open-ended concept by Grant's own disclaimer that "*organization theory lacks a rigorous … well developed and widely agreed theory of coordination*", or as Herbert Simon describes it in more extreme terms: "…'*coordination' is what we say when we don't know what we are talking about"*[3]. Grant goes on to define integration in terms of broad categories of mechanisms for coordinating knowledge between individuals depending on the interdependency of the task they need to accomplish between them, which can be summarized as 1) communication systems, documents and routine procedures for coordinating explicit information, and 2) group problem-solving for coordinating the personal know-how and experience of individuals. Grant's definition of integration is thus very much in line with contemporary views of organizational coordination as "managing dependencies between activities" using "processes of information transfer and group decision making" (Malone and Crowston 1991; Malone and Crowston 1994), so much so in fact that it makes it even harder to distinguish between what constitutes integration versus coordination.

In addition, the difficulty with Grant's approach is that it makes the operational part of integration (in other words the mechanisms of knowledge integration) as the basis for defining the concept itself rather than the other way around, where a clearly defined concept is the basis for how to operationalize it. In fairness to Grant, who is widely considered as the father of this concept and one of the pioneers of the knowledge-based view of the firm, his approach did draw clear boundaries as to what knowledge integration is not. However, the lack of clarity at the inception and early definition of the concept left the door open for many speculative and equally

[3] Even in more recent attempts at developing a theory of coordination, the authors (Malone and Crowston 1991; Malone and Crowston 1994) acknowledge the difficulty inherent in defining the concept of organizational coordination in operational terms, and provide a long list of diverse definitions commonly used in the literature.

open-ended or even conflicting definitions that followed. It is thus that many authors have come to define knowledge integration as a collection of many related and unrelated activities from knowledge creation to acquisition, transfer, storage, utilization and even maintenance of knowledge, and sometimes all at once – see for example (Yang 2005). At the other extreme, some definitions are minimalist to the point of being at an even higher level than the starting definition, where the concept of integration is simply reformulated as "absorbing" and "blending" – see for example (Balaji and Ahuja 2005). In between these two extremes are a host of definitions that confuse integration with coordination, communication, cooperation, and/or collaboration, among others. However this variety in defining the concept of knowledge integration is not all due to the lack of a clear foundational definition; it is in fact indicative of another difficulty inherent in the concept of integration itself, namely that it is indeed a multi-faceted process involving activities which are overlapping and often cannot be clearly separated[4].

But when considering the dispersed nature of knowledge in the organization, especially in large-scale organizational networks where knowledge is distributed across vast boundaries, knowledge integration becomes first and foremost synonymous with acquiring and assembling knowledge from diverse sources in the course of practice, first acquiring knowledge to where it is needed through established relationships between source and recipient, and then assembling (or combining) it with the receiver's current knowledge so that the resultant knowledge can be used to accomplish a task. Integration is therefore accomplished when the organization is able to perform a task that it could not complete with its existing knowledge alone. In this sense, the resultant (integrated) knowledge is greater than the mere combination of acquired and existing knowledge since new (additional) knowledge may be created in the combination process, as well as in the process of putting the combined knowledge to practical use. Therefore, integration by this definition is distinct from and superior to acquisition and combination alone despite any colloquial similarity in terms; the latter are in fact subsets of integration and clearly not equivalent to the complete process of integration. Thus, staying true to Grant's original intent for what constitutes knowledge integration, we offer the following conceptual definition:

[4] Merriam Webster dictionary defines integration as the process of "uniting with something else" or "incorporating into a larger unit".

Conceptual Definition for Knowledge Integration:

Knowledge integration is *bringing* diverse knowledge from multiple sources *to bear* on a complex problem or task.

The highlighted terms above embody the key ideas in the concept of knowledge integration as already posited in the existing literature. And while the term "bringing knowledge to bear" is largely conceptual, it can in fact be made operational in a number of ways that do not leave room for conflicting interpretations since it can be mapped to distinct organizational processes, namely the acquisition of new knowledge from diverse sources through established relationships between source and recipient, its combination with existing knowledge at the recipient site, and the utilization of the resultant knowledge in the course of practice. In organizational terms, acquiring knowledge translates to a process of *transfer* between source and recipient, combining knowledge translates to a process of *sharing* with different members or groups at the recipient site, and using the resultant knowledge in practice translates to a process of *applying* it to accomplish a task, which is typically in the course of problem-solving. In other words, the knowledge integration process consists of sub-processes that involve the transfer, sharing and application of knowledge in order to solve problems. We note here that a common claim in the literature is that knowledge transferred and/or shared is not necessarily appropriated or absorbed by the receiver, often due to the absence of a common knowledge base or due to syntactic or semantic differences (Cohen and Levinthal 1990; Carlile 2002). It follows that knowledge appropriation is an important aspect of the knowledge integration process, and it can be argued in principle that the integration process cannot be fully described without taking the appropriation part into consideration.

However, as noted previously in this section, the appropriation or absorption concept is very difficult to operationalize explicitly, such that it is impossible to talk about conduits or devices for knowledge absorption for example. Instead, the literature on organizational boundaries (sometimes also referred to as knowledge boundaries) incorporates the underlying factors affecting knowledge absorption, namely the differences in syntax and semantics noted above, into different types of boundaries that knowledge must be integrated across (Star 1989; Carlile 2004). As such, we include the concept of organizational boundaries as one of the main

dimensions in our definition of knowledge integration, and we assume that knowledge which has been successfully transferred across boundaries and successfully applied to solve problems has been necessarily absorbed to some degree already.

An Operational Definition for Knowledge Integration

Expanding on the conceptual definition offered above, we propose the following operational definition:

> Operational Definition for Knowledge Integration:
> Knowledge integration is the process of *transferring* knowledge, both tacit and explicit, across organizational boundaries, *sharing* it with individuals and teams at the recipient site, and *applying* the resultant knowledge to solve problems.

This definition builds on the original concept proposed in (Grant 1996a) while bounding the process of integration to clear and unambiguous sub-processes used in practice. An example of tacit knowledge integration by this definition is when multiple individuals are transferred from different organizations to form a taskforce where they share and apply knowledge together in order to accomplish a complex task. Similarly, an example of explicit knowledge integration is when previous solution information, such as a solution template, is transferred from a database and customized to solve a complex problem. Integration is therefore accomplished only when knowledge is transferred, shared and applied. As a result, integration must be inclusive of all three sub-processes and cannot be considered equivalent to knowledge transfer alone or knowledge sharing by itself for example. However, in some cases it is not necessary to carry out one or more sub-processes in order to achieve integration, such as for example when the knowledge required is already on site (e.g. resident on the team), and thus does not need to be transferred across boundaries.

The definition is scoped to include only those sub-processes which are most relevant to the concept of integration (encompassing the “where”, “what” and “how” of knowledge integration) and that are readily observable in practice (in contrast to such abstract concepts as absorbing or

blending), which makes it an operational definition free of any operational specifics as is the case in the definition proposed by Grant. In other words, the actual mechanisms for transferring, sharing and applying knowledge do not form the basis for defining what integration means, this is why they do not figure in the definition proposed here. Instead, the concept is defined independently of any of the means for "how-to" operationalize it.

Also, by this definition, integration is not identical to processes of coordination, cooperation, collaboration or communication as advanced in other definitions of knowledge integration, nor is it contradictory or exclusive of these processes (e.g. sharing or applying knowledge can be accomplished by individuals collaborating on a task, just like transferring knowledge may be accomplished by communication systems or individuals coordinating their information resources). In that sense, knowledge integration by this definition is inclusive of all of these activities without being confused with or limited to one or more of them. It is also in line with related or very similar concepts to that of integration and which are commonly adopted in the literature, such as the foundational concept of "knowledge combination" described as a process of "acquiring and using knowledge…in practice" (Brown and Duguid 1991; Kogut and Zander 1996), as well as the concept of organizational learning by exploration (of new knowledge) and exploitation (of existing knowledge) (March 1991).

In addition, the proposed definition is consistent with the widely established view that the value of knowledge is fully realized when it is interacted in a closed-loop cycle of socialization, combination, internalization and externalization known as the SECI framework for knowledge creation (Nonaka and Takeuchi 1995) since the first two (socialization and combination) are processes where knowledge is transferred and shared, while the latter (internalization and externalization) are processes by which individuals apply knowledge and learn-by-doing. Consistency between the two concepts (i.e. integration and creation) is important since new knowledge is created out of the integration process and therefore the two concepts are not entirely distinct or orthogonal. Finally, this definition is complete and purposeful in terms of highlighting the role of the knowledge integration process as an enabler of problem solving (Carlile 2002; Nickerson and Zenger 2004), and specifically in a team environment as originally proposed in (Grant 1996a).

Figure 3 below situates the concept of knowledge integration (as defined above) in the overall literature on knowledge.

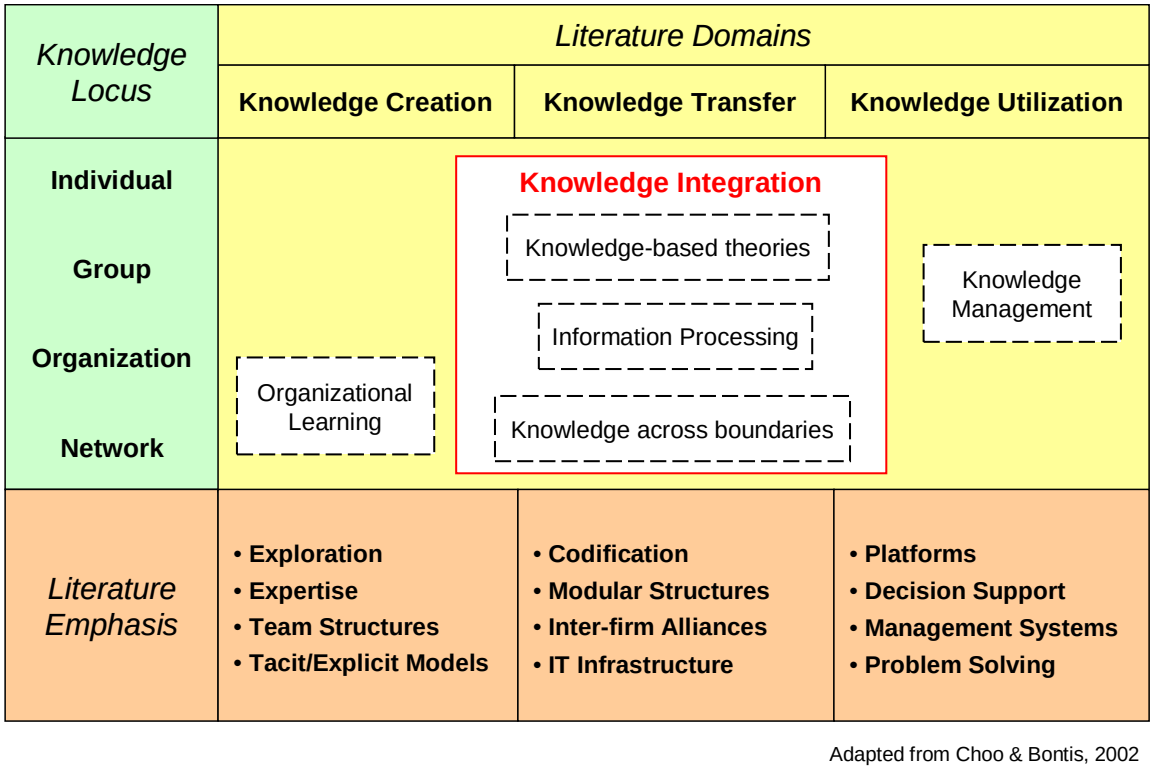

Figure 3: Knowledge Integration in the Literature

As Figure 3 illustrates, knowledge integration in the existing literature concerns itself mostly with processes of transferring / sharing knowledge across organizational boundaries, while also being connected to the utilization (or application) part of the overall literature on knowledge, and to a lesser extent with the literature on knowledge creation (since new knowledge is created out of the integration process). The operational definition for knowledge integration provided in this section is in line with the general principles advanced in these bodies of literature in terms of the fundamentals for "how" knowledge is created, transferred and utilized in an organizational context.

The "How-To" Guide for Knowledge Integration

With an operational definition of knowledge integration in hand as developed in the previous section, it is possible to investigate in detail *how* knowledge is integrated in practice, specifically in terms of the strategies/practices[5], channels and mechanisms[6] by which knowledge is transferred, shared and applied in large-scale organizational networks in order to accomplish complex tasks and to solve major problems. As already highlighted by several authors, there is a gap in the literature on framing the mechanics of the knowledge integration process in practice. According to (De Boer, Van Den Bosch et al. 1999), while knowledge integration has been explored in some detail as a concept, there is a lack of insights about what firms actually do to integrate their knowledge: *"...the use of the term combination of* (Kogut and Zander 1992) *runs parallel to the term integration used by* (Grant 1996a), *and the term configuration used by* (Henderson and Clark 1990). *What is neglected in most publications, however, is a specification of the different combination or integration mechanisms a firm has at its disposal..."* Similarly, (Hansen 2002) argues that the knowledge transfer literature *"does not shed much light on the integrative mechanisms that would allow one business unit to obtain knowledge from another."*

But despite the shortcomings pointed to above, there are some first-order insights scattered in the literature on how knowledge is integrated in practice, such as evidence about the effectiveness of systems, documents and procedures for integrating explicit knowledge, and group problem solving for integrating the skills and know-how of individuals (Grant 1996a). These insights are scarce and widely dispersed in the literature, therefore we take the approach in this paper of reviewing the literature extensively with an eye for the "how-to" of knowledge search, transfer, sharing and application, in order to shed light on the different constituents of the integration process and ultimately to better understand how knowledge is integrated in practice. We begin by reviewing a sample of seminal studies as shown in Table 1 below. This table presents an overview of the most cited and most recent literature relevant to the operational aspects of knowledge integration, illustrating the major insights from various perspectives on the topic.

[5] The terms "strategies" and "practices" are used interchangeably in this paper to refer to broad action plans set by an organization with a primary or ultimate objective of integrating knowledge (e.g. a strategy of knowledge reuse or a practice of sharing lessons learned).

[6] The term "mechanism" is used to refer to the specific means by which knowledge is integrated under a particular strategy/practice (e.g. a database of lessons learned).

Table 1: Overview of the Literature on Knowledge Integration

Reference	Focus	Method	Relevant Conclusions/Results
Ancona & Caldwell, 1992	External team interactions with the environment	Conceptual & Hypothesis-test	Vertical negotiation and horizontal task coordination as well as scouting for technical knowledge increase team performance
Aoshima, 2002	Knowledge transfer across product generations	Hypothesis-test	Transfer system knowledge by job rotations; transfer component knowledge by documents and information systems
Carlile, 2004	Knowledge integration across syntactic, semantic and pragmatic boundaries	Conceptual & Empirical	IT systems, liaison individuals and negotiators or modelers to transfer, translate and transform knowledge respectively
De Boer et.al, 1999	Knowledge integration as a function of organizational forms and capabilities	Conceptual & Case-study	Integrating design and architectural knowledge relies on the firm's socialization, coordination and information systems capabilities
Dyer & Nobeoka, 2000	Knowledge integration through collective learning routines across organizations	Conceptual & Empirical	Network-wide communities, people rotation, dedicated resources and free assistance to members increase network learning
Edmondson & Sole, 2002	Knowledge integration to bridge gaps across geographically dispersed IPT's	Conceptual & Case-study	IPT members compensate for knowledge gaps by drawing on broader and deeper expertise and skills in communities of practice
Grant, 1996 (a)	Knowledge integration as the basis for the knowledge-based theory of the firm	Conceptual	Efficient knowledge integration by using multiple informal and formal mechanisms, tacit and explicit, flexibly and simultaneously
Grant, 1996 (b)	Knowledge integration as the means for evolving organizational capability	Conceptual	Tacit knowledge is integrated by routine tasks and activities, explicit knowledge by codified directives, procedures, technology
Hansen, 2002	Knowledge integration across team boundaries in an organizational network	Conceptual & Hypothesis-test	Direct inter-team connections are beneficial for transferring tacit knowledge, but inefficient for transferring codified knowledge
Hoopes & Postrel, 1999	Product development performance as a function of intra-firm knowledge integration	Conceptual & Case-study	Increasing product complexity requires increased knowledge sharing across boundaries and early specs development
Nonaka & Takeuchi, 1995	Creating new knowledge through a cycle of articulating, sharing, combining, absorbing	Conceptual	Knowledge must spiral up from individuals to groups and across organizational boundaries in order to realize its value
Okhuysen & Eisenhardt, 2002	Formal interventions for improving group flexibility and knowledge integration	Hypothesis-test	Questioning others enables knowledge integration in groups, while information sharing internally has little to no impact
Szulanski, 1996	Impediments to knowledge transfer inside the organization	Conceptual & Empirical	Knowledge ambiguity, lack of trust and arm's length relationships impede the transfer of knowledge inside the organization

Building on the important insights highlighted in Table 1, we frame below the most relevant findings in the literature relating to how knowledge is integrated in practice; specifically, we characterize and classify the different strategies, practices, channels and mechanisms for integrating different types of knowledge across internal and external organizational boundaries.

Tacit vs. Explicit Knowledge Integration

As already introduced at the outset of this paper, one of the most useful and commonly discussed themes in the literature on knowledge in organizations is the distinction between tacit and explicit knowledge (Nonaka and Takeuchi 1995; Spender 1996; Grant 1996a; Hansen, Nohria et al. 1999). In categorizing knowledge based on its many different types, the tacit and explicit characterizations are the two foremost dimensions by which every other kind of knowledge can be further classified, from design knowledge to business knowledge and others. (Polanyi 1966) is widely considered to be the authoritative source on the concept of tacit knowledge which he defines as personal knowledge acquired through experience and which is inseparable from an individual's aptitude, beliefs and commitment. In that sense tacit knowing is like riding a bicycle, it is knowledge acquired through experience and becomes an innate skill that we cannot easily describe to others except through personal demonstration. This is why Polanyi argues that tacit knowledge is difficult to transfer to others, something he explains with a famous quote when he says of people: "*we know more than we can tell*" (Polanyi, 1966: p.4). In contrast, explicit knowledge is the part of knowledge that is readily articulated and has been or can be captured in written or electronic format (Nonaka and Takeuchi 1995; Spender 1996), such as low-level information in the form of raw data, or situated information in the form of scientific principles.

To illustrate the fine distinction between tacit and explicit knowledge in practice, consider the recent real-life troubleshooting event in July of 2005 where NASA, a very large-scale organization with massive information resources especially in terms of documented rules and procedures, was unable to troubleshoot a fuel sensor malfunction until the retired engineer who designed part of the system 30 years earlier was brought out of retirement to help diagnose the

problem[7]. This is because the knowledge that individuals accrue through long years of experience and specialization, as well as their innate skills at specific tasks, are often difficult to capture and pass on as codified information. This example shows that tacit knowledge is different from and more valuable than explicit knowledge, without the two being completely independent of each other. To further illustrate this distinction with a more common example, consider the difference between the information found in a cookbook (i.e. the steps in a recipe) and the cooking knowledge of the chef (i.e. the skills and accumulated know-how of the cook). Following a recipe or knowing many recipes does not necessarily make one a great chef; instead it is the innate skills developed over time and the experience from deductions and interpretations through analysis, trial-and-error and learning-by-doing that distinguish a great chef who can create great tasting food from an ordinary cook who can only create ordinary tasting food. Similarly, the distinction between a junior engineer and a senior engineer is not only measured in terms of the amount of information each one retains (indeed a junior engineer may have memorized more information from books and manuals than a senior engineer). However it is the experience of the latter in analyzing and interpreting facts and deducing insights from information that separates his or her skill level from that of a junior engineer (Vincenti 1990).

There is wide agreement in the literature as well as in practice that tacit knowledge is more valuable for organizations than explicit knowledge, since the latter can be easily obtained from books and databases, whereas tacit knowledge is held by individuals who take it with them when they leave the organization (Nonaka and Takeuchi 1995; Grant 1996b). The value of tacit knowledge becomes even more relevant in high technology environments where explicit knowledge becomes obsolete very quickly (Prusak 1996; Davenport and Prusak 1998). Tacit knowledge is also considered as the real source of competitive advantage since it is difficult to imitate (Nonaka and Takeuchi 1995; Prusak 1996; Spender 1996), whereas knowledge that has been codified can be readily absorbed by others (Takeuchi and Nonaka 2004). It is however argued that both tacit and explicit knowledge are interdependent and inseparable (Brown and Duguid 2001), and that they are complementary in terms of their usefulness for production, so that the presence of both is necessary for competitive advantage as they are the two essential components in the process of creating new knowledge (Nonaka and Takeuchi 1995). More

[7] **http://edition.cnn.com/2005/TECH/space/07/19/space.shuttle/index.html** - accessed Feb. 15, 2009

simply put, an organization without experienced and highly skilled employees would not be able to compete, while an organization without procedure manuals or computer software would not be able to produce.

When it comes to knowledge integration, there are different views in the literature on how much of tacit knowledge is transferable or shareable, with most authors arguing that at least a part of an individual's tacit knowledge can be transferred and shared with others through observation (such as watching a an artist draw) or learning-by-doing (as in attempting to draw under the artist's supervision), while a minority argue that tacit knowledge is personal skill that is acquired with little help from others and that it cannot be taught (Gourlay 2006). But despite some differences in the extant literature, there is general consensus that valuable tacit knowledge may be integrated effectively in organizational settings through personal interaction such as face-to-face communication and group interaction (Aoshima 2002; Carlile 2004). In contrast there is wide consensus on the fact that all explicit knowledge can be easily transferred and shared through documents and information systems (Hansen, Nohria et al. 1999), making it also easy to imitate by competitors (Grant 1996b).

Syntactic vs. Semantic vs. Pragmatic Knowledge Integration

Since knowledge used in production is information supplemented with context and experience (Nonaka and Takeuchi 1995; Grant 1996a), it is by definition embedded in its context, such as the technical know-how embedded in a particular practice (as manifested in communities of practice (Brown and Duguid 1991)), or knowledge that is technology-specific or product-specific (Henderson and Clark 1990). This means that there are contextual boundaries separating different knowledge domains, which adds a new dimension to the knowledge integration process in that it necessitates the use of special types of mechanisms to interpret and transform knowledge before it can be transferred across different knowledge boundaries. These mechanisms are known as "boundary objects" and "liaison devices" and serve to establish a shared context across boundaries (Star 1989; Carlile 2002; Carlile 2004).

There are typically three types of knowledge boundaries in organizations: the syntactic (pertaining to differences in syntax or language), the semantic (relating to differences in interpretations) and the pragmatic (involving differences in functional specializations and interests) (Carlile 2002; Carlile 2004). There are four categories of boundary objects that map to the three different types of knowledge boundaries: 1) database repositories that provide a shared syntax for *transferring* knowledge across syntactic boundaries, 2) standardized forms and methods that provide a shared format for *translating* knowledge across semantic boundaries, 3) models (such as drawings, prototypes and computer simulations) for *negotiating and transforming* knowledge dependencies across pragmatic boundaries, and 4) maps (such as scheduling charts, process maps and workflow diagrams) for *representing and clarifying* knowledge dependencies across pragmatic boundaries (Star 1989; Carlile 2002). The third and fourth categories of boundary objects are considered to be of similar nature and purpose and are often combined together (Carlile 2002). In addition, while most boundary objects are distinct in terms of their nature and purpose, they are nonetheless complementary in terms of their usefulness for knowledge integration in that using one mechanism can serve to support the effectiveness of using another (e.g. using models and maps can enhance the content of shared repositories, and vice-versa). Furthermore, each object can be useful across more than the one type of boundary it is mapped against. For example, all boundary objects are considered useful in mediating shared syntax, even if not as effectively as repositories are (Carlile 2002).

The main insights from this literature are that differences in knowledge contexts constitute different types of knowledge boundaries that require particular types of mechanisms for mediating knowledge across them. As such, it is important for organizations to have a portfolio of boundary objects at their disposal in order to efficiently and effectively integrate knowledge in different environments. This is particularly important in the large-scale development of complex systems where the knowledge that is embodied in these systems is increasingly diverse (from different disciplines) and specialized (from different practice domains), and where more organizations with different lingo, interpretations and interests are involved in the development process (Carlile and Rebentisch 2003).

"Sticky" vs. "Leaky" Knowledge Integration

Knowledge in organizations is said to have a "sticky" characteristic (Von Hippel 1994; Szulanski 1996), in that it is difficult to integrate (costly to transfer, share and use) between source and recipient. This is due to the fact that knowledge most relevant for production is mostly tacit (as discussed in § 2.1.2), and that differences in syntax, interpretation or interests may pose a barrier to efficient and effective integration (Cohen and Levinthal 1990; Carlile 2002). But it is also argued that knowledge has a "leaky" or "mobile" characteristic (Hoopes and Postrel 1999), which is the opposite of "sticky" in that it's easy to lose proprietary knowledge across porous external boundaries with competitors. (Brown and Duguid 2001) explain this dichotomy by noting that stickiness is triggered by the internal division of labor inside large-scale organizations, where internal boundaries make it hard to transfer knowledge between different communities of practice (e.g. between engineering and manufacturing), whereas leakiness is triggered by the unifying effect of the external network that the organization is part of, since networks by definition unify different organizations with a core of common practices.

(Von Hippel 1994) outlines five different strategies for integrating sticky knowledge, as follows: 1) moving the required knowledge to where the problem or task is located – described by Von Hippel as "visiting the plant"; 2) moving the problem or task to where the required knowledge is located – described as "relocating the plant"; 3) iterating between multiple knowledge sites if the required knowledge is located at more than one site – described as "plant-to-lab and lab-to-plant trips"; 4) partitioning the problem or task into sub-problems or sub-tasks that each draw on only one locus of sticky knowledge – described as the "Firm X – Firm Y partition"; and, 5) reducing the stickiness of the required knowledge, described as "tacit-to-explicit knowledge conversion…using expert systems and…computer databases".

Expanding Von Hippel's illustration of the five knowledge integration strategies into actual mechanisms, it can be inferred that the implementation of each of the above strategies in a large-scale organizational context would require the following types of integration mechanisms, respectively: 1) site visits, co-location, liaison devices, boundary objects, taskforces, team meetings, people transfers and dispatching of subject matter experts to move knowledge to the

problem locus; 2) co-location, prototypes and simulation (both of which can also be considered boundary objects) and off-site (laboratory) testing to move the problem to the knowledge site; 3) shared databases and integrated design tools to reduce the stickiness of knowledge; 4) same mechanisms as in option 2 to iterate between knowledge sites; and 5) same mechanisms as in option 1 to partition the problem, but used across intra- and inter-firm boundaries. In a large-scale complex problem solving context, the required knowledge is likely to be located at more than one site, therefore strategies 2) and 3) become less efficient and/or effective due to the cost and difficulty of moving the problem to multiple knowledge sites and iterating between them to solve the problem.

Other important mechanisms for overcoming knowledge stickiness are those that facilitate the mobility or leakiness of knowledge, meaning those mechanisms that are used to integrate knowledge across external boundaries (including prime-supplier, program-program or program-function boundaries), namely networks of practice (or communities of communities of practice) and the social networks of individuals, both of which serve to establish a common knowledge base between people regardless of their location within the same or different organizations (Brown and Duguid 2001). These insights can be reframed as in Table 2 below:

Table 2: Knowledge Integration over Insulated and Porous Boundaries

Knowledge Characteristics	Boundary Characteristics	Knowledge Integration Characteristics
Leaky	External porous (e.g. program-function)	Communities of practice, networks of practice, social networking
Sticky	Internal insulated (e.g. program-program)	Job rotation, moving experts, shared or integrated systems, liaison devices, boundary objects, team meetings
Sticky	External insulated (e.g. prime-supplier)	Site visits, co-location, taskforces, shared systems

The usefulness of the sticky / leaky distinction in this context is in pointing to the counterintuitive role of organizational culture in segregating knowledge inside the one organization, while unifying it across different organizations. This is in contrast to the common wisdom which suggests that culture ties all the members of an organization together through a

shared vision and beliefs regardless of their practice, whereas cultural differences across organizations separate even those individuals who share the same practice. However , from the perspective of integrating knowledge, when considering that a technician and a systems engineer in the same organization have little shared knowledge in common, whereas systems engineers in different organizations have a lot of knowledge in common, it becomes apparent that organizations cannot be considered as single communities of practice tied by the organization's culture, they are in fact a collection of many and often distinct communities of practice with different knowledge contexts and different sub-cultures (i.e. the organization from this perspective is a community of communities (Brown and Duguid 1991)). In that sense, the knowledge integration process should not only be concerned with bridging differences related to the nature of knowledge itself (such as differences in syntax between differently specialized teams), but also with bridging the internal compartmentalization of practice inside the same organization, such as between different programs in a single firm, or between teams at different levels in the same program (e.g. a subsystem level team versus a system-level team).

The main conclusion from this literature for the purposes of this paper is that knowledge can be sticky even within the smaller confines of a single program or firm; therefore it is important to recognize that knowledge should be integrated across both internal and external boundaries, and that external boundaries are porous both ways, such that a protectionist policy against leaking knowledge to the larger external network of practice is counterproductive as it will inhibit the reverse integration of knowledge from the network to the firm across those same boundaries. Instead, instituting a strong identity and shared purpose at the level of the network of practice that the organization is embedded in can leverage the leakiness of knowledge and enhance its integration.

Direct vs. Indirect Knowledge Integration

(Hansen 2002) characterizes knowledge integration channels as either direct or indirect, where direct channels are those that provide immediate access to knowledge without going through intermediate connections, whereas indirect channels are those that go through intermediaries, such as boundary spanners or gatekeepers, in order to access knowledge from another source.

The difference between direct and indirect channels is in the relative degree of their usefulness in the knowledge integration process, both in terms of efficiency (speed and cost of integration) and effectiveness (ease of absorption and relevance of the integrated knowledge to the problem).

Based on the concept of absorptive capacity advanced by (Cohen and Levinthal 1990), it is argued that direct channels between teams are most efficient for transferring tacit knowledge which is difficult to articulate and therefore more difficult to absorb than explicit knowledge. In such cases, effective mechanisms are individual face-to-face interactions or team meetings where knowledge about new technologies or product-specific technical know-how are quickly and more easily articulated and transferred from the source to the recipient. Indirect channels in such cases are only effective for identifying potential knowledge sources, but they are considered ineffective for integrating tacit knowledge due to the potential of distortion by intermediaries as they interpret the knowledge between source and recipient. (Hansen 2002) demonstrates that 1) the more direct channels a team has for integrating tacit knowledge, the more efficient they will be at accomplishing their task, and 2) the less intermediate connections an indirect channel has to go through, the more efficient the team will be in acquiring knowledge to accomplish their task. It is important to note here that the direct/indirect distinction pertains only to tacit knowledge integration, since codified knowledge can be readily integrated through conduits in the organization's infrastructure such as information systems and documents.

Another perspective in the literature on the direct / indirect dimension is briefly discussed by (De Boer, Van Den Bosch et al. 1999) where knowledge integration is characterized as a process that can be directly or indirectly accomplished. Direct knowledge integration is defined as pre-designed integration where the expected outcome is pre-determined, such as integration using systems, manuals and policies specifically designed by the organization to accomplish a certain level of explicit knowledge integration. In that sense, direct is synonymous with *directed* integration. Indirect integration is defined as a guided (as opposed to directed) process where the outcome of integration is not pre-determined, and which involves autonomous agents, such as in the formal training and education of personnel or the establishment of formal liaison devices.

In summary, we conclude that tacit knowledge integration is most efficiently accomplished by establishing several direct channels between different parts of the organization, supplemented by a social network of indirect channels with short paths lengths (i.e. few intermediaries). Similarly, explicit knowledge integration is best accomplished through directed channels and mechanisms pre-established by the organization, supplemented by formal training of personnel.

Formal vs. Informal Knowledge Integration

Knowledge is interacted within and between organizations through formal and informal instruments (i.e. the channels and mechanisms by which knowledge is flowed). Formalized instruments are those instituted by the organization for the purposes of transferring, sharing and applying knowledge, while informal channels are those created and maintained by individual members of the organization (Davenport and Prusak 1998). Both types of instruments are considered of equal importance from the perspective of knowledge integration, where informal channels and mechanisms serve to complement the formalized ones, and as such they both are necessary components of the knowledge integration process (Grant 1996a). Their advantages and disadvantages vary depending on the organizational context and the circumstances governing the knowledge integration process. A good summary of the typical strengths and drawbacks of formal versus informal instruments is given by (Davenport and Prusak 1998): "…the main advantage of informal networks is that they are self-updating and adaptive since they consist of people continuously interacting with each other…In contrast, more formal systems such as electronic repositories become stale as soon as they are established."

Examples of formalized channels for transferring and sharing knowledge are the coordination links embedded in organizational hierarchies where by virtue of one entity reporting to another, knowledge is formally and routinely flowed between them (Grant 1996a). Formalized channels for transfer and sharing as well as for applying knowledge are also embedded in the infrastructure of the organization, such as the numerous facilities and systems typically provided for carrying out tasks and activities, from conference rooms to information systems. (Galbraith 1974) identified liaison devices, task forces and permanent committees as some of the key formal mechanisms for integrating knowledge across multiple teams in an organization. Other

examples of formal mechanisms instituted along formal channels are routine or regular meetings, official directives, databases, communities of practice, among countless others.

Examples of informal channels are the personal networks and relationships between individuals that are either created and/or maintained by those individuals with little or no formalization by the organization. The mechanisms employed along informal channels are also informal in nature, with some of the more common examples including online communities, after-hours socializing, or even what is known as the "grapevine" in reference to indirect communication channels inside the organization (Johnson, Donohue et al. 1994). Both formal and informal channels can be intra- as well as inter-organizational. However due to the competitive nature of inter-firm relationships, formalized channels are more dominant, such as formalized prime-supplier communication channels through legal contracts, site visits, and shared databases.

Vertical vs. Horizontal Knowledge Integration

(Demsetz 1988) and (Grant 1996a) define organizational boundaries in terms of knowledge dependencies between different stages of production along two dimensions, namely the horizontal (across different specialties or different projects in the same organization) and vertical (across different organizations or different hierarchies in the same organization). They argue that vertically linked stages of production A and B will be integrated within the same firm if production at stage B requires access to knowledge utilized in stage A, as is the case in the development of tightly interconnected products which are more efficiently developed in-house (efficiency here is equivalent to minimizing high coordination costs across organizational boundaries (Christensen, Verlinden et al. 1999)). In this case, vertical knowledge integration would be internal to the firm, such as between engineering and manufacturing, or between subsystem level and system level teams inside the same program. Otherwise if stage B output can be accomplished independently of stage A, then production can take place in separate firms, as is the case in the development of modular systems where some parts of the system are efficiently outsourced to suppliers as separate modules (Baldwin and Clark 1997). In this case, vertical knowledge integration would be along a channel linking prime and supplier organizations.

Similarly, it is argued that horizontal integration will take place within a single firm in cases of knowledge interdependence between two parallel stages of production, as is the case in multi-product firms (Nobeoka and Cusumano 1994). In this case, horizontal knowledge integration would be between different programs within the same organization. In related lines of research, scholars have also demonstrated the importance of having horizontal linkages between different subunits within the same organization in order to have effective coordination and open knowledge sharing internally. This research has shown that a subunit's information processing capacity is enhanced by horizontal inter-unit integration mechanisms (Galbraith 1974; Hansen, Nohria et al. 1999; Gupta and Govindarajan 2000).

However, the current literature is silent on horizontal integration inside a single function or program, such as would be the case between different system teams or between multiple subsystem teams belonging to the same program. This is because of a common assumption in the current literature that integration takes place across traditional organizational boundaries such as those separating the firm and its environment or market (Santos and Eisenhardt 2005), or those separating different organizational entities within the same firm (Clark and Fujimoto 1991), as in integration across different functions (for example, between engineering and manufacturing), across different programs or projects (for example, integration between different generations of the same product or between independent product lines (Nobeoka 1993)), across different vertical layers in the organizational hierarchy (for example, between management and production), or altogether different and independent organizations (for example, between prime and supplier (Takeishi 2001)). As such, the concept of integration as framed in the literature does not explicitly address the horizontal boundaries between subunits or teams within the same entity and at the same level in the hierarchy, such as system-level or subsystem-level teams belonging to the same program. This is due to the continuing dominance of the static view in the literature which frames the firm in terms of its conventional divisions, thus limiting the extent of horizontal integration to one between traditional or economically separate entities (Foss 1996a). But this does not reflect the reality of knowledge integration in complex product development for example, where large system and subsystem teams often constitute separate autonomous entities even within the same program or function (Browning 1997). In this context, the knowledge

integration picture would not be complete without taking into account the horizontal channels linking different teams within the same program or function.

An example of inter-team horizontal knowledge integration is typically seen in the development of hybrid "modular-integral" systems where functional interdependencies between subsystem modules are complex enough that they cannot be fully specified and easily assembled without extensive horizontal interactions between the different subsystem teams. In these cases which are common in the development of highly complex and customized products such as aerospace systems (Moir and Seabridge 2006), different teams develop different subsystem modules separately, but are forced to interact together extensively during system integration in order to troubleshoot emergent problems due to the complex interdependencies between the different subsystems. Thus, most of the knowledge integrated at that stage is along the horizontal channels inside the same program at the subsystem team level.

To further complete the characterization of knowledge integration along the vertical and horizontal dimensions, we note the related concept of lateral linkages which is not tackled in the literature on knowledge integration, or which is used synonymously with horizontal relationships[8] – for example in (Galbraith 1974). Similarly, (Gupta and Govindarajan 2000) use "lateral" linkages in the same vein as horizontal relationships where they define lateral socialization mechanisms as those between "peer" nodes or units, such as horizontal personnel transfers inside the same organization. The closest attempt at discussing lateral linkages for integrating knowledge separately from horizontal relationships is found in (De Boer, Van Den Bosch et al. 1999), who define lateral knowledge integration as coordination and communication channels that cut across lines of authority, with mechanisms such as liaison devices between individuals or groups. By this definition, lateral integration channels can be considered as those crossing intra-firm boundaries to connect different entities at various levels of the hierarchy, with the purpose of bridging gaps in tacit knowledge and expertise. Building on these insights, we define lateral linkages as specifically those channels linking programs and functions, where the

[8] Merriam Webster defines "lateral" as *directed toward, or coming from the side*, while "horizontal" is defined as *directed toward individuals or entities of similar status on the same level*. It is common to see the two concepts used interchangeably in organization research – see for example (Tushman and Nadler, 1978) and (Hansen, 2002). We classify lateral linkages (such as the links between programs and functions) separately from horizontal links (as those between two programs or two teams in the same program) and independently of hierarchical (vertical) order.

latter supply new knowledge to programs through mechanisms such as people rotation and liaison devices as suggested in the literature. In a product development context, functional personnel are domain specialists with deep expertise and up-to-date knowledge, which makes lateral linkages under this definition more likely to be used for integrating new tacit knowledge held by individual experts. Lateral linkages are therefore most useful in the development of complex and high technology products due to the increasing breadth and depth of disciplinary knowledge required to develop such products as well as the need for more up-to-date knowledge in these new technology environments (Allen 2000).

With a more complete picture of the vertical, horizontal and lateral dimensions for knowledge integration, we can conclude that knowledge integration in large-scale organizational environments takes place *simultaneously* along all three types of channels, but with varying emphasis based on the level of knowledge dependence between the different tasks being performed. Thus, in order to determine the ideal paths and mechanisms for knowledge integration in a particular context, it is important to look at the levels and characteristics of knowledge dependence between different production stages and tasks.

Firm vs. Network Knowledge Integration

The knowledge-based view of the firm (Kogut and Zander 1992; Grant 1996a) argues that firms are more efficient than markets at integrating tacit and explicit knowledge due to their collective coordination and communication mechanisms (i.e. the infrastructure) and a unifying organizational culture (e.g. shared values, goals and vision) that fosters collaboration. It then naturally follows that a network of several firms with a shared purpose would have more knowledge and more integrating mechanisms at its disposal than a single firm and hence would be superior at integrating knowledge than a single firm. Such a network would be different from a collection of traditional buyer-supplier relationships which are typically vertical, one way and at arm's length. Instead, an inter-organizational network is a collection of "peers" where relationships are many-to-many instead of one-to-many, and where network flows can involve technology and know-how exchanges, joint activities, cooperative research, and collaborative marketing arrangements, among others (Grant and Baden-Fuller 1995).

However, there are many barriers that prevent networks from openly integrating their knowledge resources for the collective good of all members, most important of which are the proprietary barriers designed to protect each firm's knowledge from being imitated by outsiders. In a study of Toyota's high-performing network, (Dyer and Nobeoka 2000) identified three major dilemmas facing knowledge sharing in a network setting as: 1) proprietary barriers, 2) free-rider problems and 3) network infrastructure issues. The authors outlined four main strategies, practices and mechanisms that the Toyota Group uses to overcome these dilemmas, namely: 1) a network level association for sharing information through regular meetings, mutual training and socializing events; 2) a coordinating unit responsible for knowledge acquisition, storage and diffusion through free on-site assistance to network members, 3) sub-network level forums for specialized knowledge sharing in small groups of members, and 4) inter-firm employee transfers. The combined strategies and mechanisms establish a versatile infrastructure of multi-lateral relationships between all members, providing each one with superior benefits from participating in the network, thus incentivizing the members to overcome their silo mentality maintained by each one's proprietary issues. These strategies and mechanisms also foster norms of reciprocity between members, where being helped with a problem is contingent on one's commitment to helping others.

At first glance, one is tempted to believe that the Toyota model is based mostly on fostering "good intentions" between members, as perhaps best illustrated by the motto of the Four Musketeers "all for one and one for all". However, underlying this collaborative environment is a carrot-and-stick approach by Toyota where financial and other penalties are enforced against members who do not abide by the rules and norms of the network. This indicates that a strong shared identity and purpose among network members is not as easily implemented as in the single firm. As such, a network of organizations cannot be considered a true peer-to-peer arrangement like the open sharing "P2P" networks linking users of modern computers, rather there is always a need for leadership by a prime organization to mediate, facilitate and oversee the network to some degree, depending on internal and external factors such as network architecture and market forces for example (Gomes-Casseres 1994).

Inter-organizational networks are increasingly common in manufacturing and product development due to the increasing demands for quality and capability in even the simplest of products, which translates to an increasing need for a wide variety of discipline-specific knowledge along with the need for deep specialization in multiple knowledge domains. As a result, organizations are less and less able to find all the knowledge they need within their own walls, and are faced with growing reliance on outside suppliers to provide the specialized knowledge required for the design and development of different parts of their product (Prencipe 2000). This is especially true in the development of complex systems where the required technical knowledge and expertise are more and more dispersed across large-scale networks of multi-tiered suppliers. This means that knowledge integration in complex product development is no longer confined to the walls of a single firm or to bilateral channels between prime and supplier, but can also encompass entire networks composed of multiple organizations at different levels or tiers in the network. It then follows that the framing of knowledge integration in a complex product development context cannot be firm-centric only, and needs to account for the different strategies, channels and mechanisms that are useful in a network context.

Finally, it is important to note that while there are tangible benefits from network participation such as increasing performance in terms of increased quality, productivity and reduced inventory as has been shown in previous research (Dyer and Nobeoka 2000), there are nonetheless disadvantages inherent in network arrangements, such as knowledge dependence by smaller members on the lead or central firm in the network (Gomes-Casseres 1994), or rippling problems from one or more parts of the network which end up affecting other member firms directly or indirectly (e.g. if a new member upsets the balance of internal competition with an existing member, the benefits from network participation would decline not only for the two affected members but possibly for the entire network due to the decline in performance by two of its members). In summary, the main insight from the firm / network distinction in the literature is that while the single firm is generally most efficient at integrating tacit and explicit knowledge within its walls, it is nonetheless not as effective at knowledge integration as a network of multiple organizations tied together through a strong shared identity, norms and rules.

Conclusion

In this paper we have addressed the theoretical gaps in the literature on knowledge integration by: a) proposing clear definitions for the integration process at both the conceptual and operational levels; and b) identifying and classifying the main strategies, practices, channels and mechanisms for integrating knowledge in practice, which are summarized in Table 3 below.

Table 3: Knowledge Integration by Knowledge and Organizational Characteristics

Knowledge Characteristics	**Org. Boundary Characteristics**	**Knowledge Integration Characteristics*** (* Only the primary channels and mechanisms are shown)
Tacit	--	Face-to-face communication, group interaction
Explicit		Documents, information systems
Sticky	Internal, External	Site visits, co-location, liaison devices, boundary objects
Leaky	External	Networks of practice, individual social networks
	Syntactic	Database repositories
	Semantic	Standardized forms
	Pragmatic	Models/prototypes, drawings, simulations, maps
	Direct	Team or individual meetings face-to-face
	Indirect	Social or organizational networks
	Formal	Teams and taskforces, liaison devices, meetings, information systems, boundary objects, mediators
	Informal	Personal networks, online communities of practice
	Vertical	Integration between subsystem-system teams, prime-supplier
	Horizontal	Intra-program, program-program, peer-peer integration
	Lateral	Program-function integration
	Firm	Organizational culture, infrastructure
	Network	Network identity, facilitator groups, rules

REFERENCES

Allen, T. J. (2000). Organizational Structure for Product Development. MIT Sloan School of Management.

Aoshima, Y. (2002). "Transfer of System Knowledge Across Generations in New Product Development: Empirical Observations from Japanese Automobile Development." Industrial Relations **41**(4): 605-628.

Argote, L. (1999). Organizational learning : creating, retaining, and transferring knowledge. Boston, Kluwer Academic.

Balaji, S. and M. K. Ahuja (2005). Critical Team-Level Success Factors of Offshore Outsourced Projects: A Knowledge Integration Perspective. HICSS '05. Proceedings of the 38th Annual Hawaii International Conference on System Sciences. Hawaii, IEEE Computer Society.

Baldwin, C. Y. and K. B. Clark (1997). "Managing in an Age of Modularity." Harvard Business Review.

Brown, J. S. and P. Duguid (1991). "Organizational learning and communities of practice: Toward a unified view of working, learning and innovation." Organization Science **2**(1, Special Issue: Organizational Learning: Papers in Honor of (and by) James G. March): 40-57. .

Brown, J. S. and P. Duguid (2001). "Knowledge and Organization: A Social-Practice Perspective." Organization Science **12**(2): 198-213.

Browning, T. R. (1997). Exploring Integrative Mechanisms with a View Towards Design for Integration. Fourth ISPE International Conference on Concurrent Engineering: Research and Applications.

Carlile, P. R. (2002). "A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development." Organization Science **13**(4): 442-455.

Carlile, P. R. (2004). "Transferring, Translating, and Transforming: An Integrative Framework for Managing Knowledge Across Boundaries." Organization Science **15**(5): 555-568.

Carlile, P. R. and E. S. Rebentisch (2003). "Into the Black Box: The Knowledge Transformation Cycle." Management Science **49**(9): 1180-1195.

Christensen, C., M. Verlinden, et al. (1999). Product Modularity, Vertical Disintegration and the Diffusion of Competence, Harvard Business School**:** 99-124.

Clark, K. B. and T. Fujimoto (1991). Product Development Performance: Strategy, Organization and Management in the World Auto Industry. Boston, Massachusetts, Harvard Business School Press.

Cohen, W. M. and D. A. Levinthal (1990). "Absorptive Capacity: A New Perspective on Learning and Innovation." Administrative Science Quarterly **35(**1, Special Issue: Technology, Organizations, and Innovation): 128-152. .

Conner, K. R. and C. K. Prahalad (1996). "A Resource-Based Theory of the Firm: Knowledge versus Opportunism." Organization Science **7**(5): 477-501.

Davenport, T. and L. Prusak (1998). Working Knowledge: How Organizations Manage What They Know, Harvard Business School Press.

De Boer, M., F. A. J. Van Den Bosch, et al. (1999). "Managing Organizational Knowledge Integration in the Emerging Multimedia Complex." Journal of Management Studies **36**(3): 379-398.

Demsetz, H. (1988). "The Theory of the Firm Revisited." Journal of Law, Economics, & Organization **4**(1): 141-161.

Dyer, J. H. and K. Nobeoka (2000). "Creating and Managing a High-Performance Knowledge-Sharing Network: The Toyota Case." Strategic Management Journal **21**(3): 345-367.

Foss, N. J. (1993). "Theories of the firm: contractual and competence perspectives." Journal of Evolutionary Economics **3**(2): 18.

Foss, N. J. (1996a). "Knowledge-Based Approaches to the Theory of the Firm: Some Critical Comments " Organization Science **7**(5): 470-476

Galbraith, J. R. (1974). Organizational Design: An Information Processing View, M. Wiener.

Gomes-Casseres, B. (1994). "Group versus group: How alliance networks compete." Harvard Business Review **72**(4): 62-74.

Gourlay, S. (2006). "Towards conceptual clarity for ‘tacit knowledge’: a review of empirical studies." Knowledge Management Research & Practice **4**: 60–69.

Grant, R. M. (1996a). "Toward a Knowledge-Based Theory of the Firm." Strategic Management Journal **17**(Winter Special Issue): 109-122.

Grant, R. M. (1996b). "Prospering in Dynamically Competitive Environments: Organizational Capability as Knowledge Integration." Organization Science **7**(4): 375-387.

Grant, R. M. and C. Baden-Fuller (1995). "A knowledge-based theory of inter-firm collaboration." Academy of Management **Best Paper Proceedings**: 17-21.

Gupta, A. K. and V. Govindarajan (2000). "Knowledge flows within multinational corporations." Strategic Management Journal **21**(4): 473-496.

Hansen, M. T. (2002). "Knowledge Networks: Explaining Effective Knowledge Sharing in Multiunit Companies." Organization Science **13**(3): 232-248.

Hansen, M. T., N. Nohria, et al. (1999). "What's your Strategy for Managing Knowledge." Harvard Business Review: 106-116.

Henderson, R. and K. Clark (1990). "Architectural Innovation: The Reconfiguration Of Existing Product Technologies and the Failure of Established Firms." Administrative Science Quarterly **35**(1): 9-30.

Hoopes, D. G. and S. Postrel (1999). "Shared Knowledge, "Glitches," and Product Development Performance." Strategic Management Journal **20**(9): 837-865.

Johnson, J. D., W. A. Donohue, et al. (1994). "Differences Between Formal and Informal Communication Channels." Journal of Business Communication **31**: 111-122.

Kogut, B. and U. Zander (1992). "Knowledge of the Firm, Combinative Capabilities, and the Replication of Technology." Organization Science **3 Focused Issue: Management of Technology**(3): 383-397.

Kogut, B. and U. Zander (1996). "What Firms Do? Coordination, Identity, and Learning." Organization Science **7**(5): 502-518.

Malone, T. W. and K. Crowston (1991). "Toward an interdisciplinary theory of coordination."

Malone, T. W. and K. Crowston (1994). "The interdisciplinary study of coordination." ACM Computing Surveys (CSUR) **26**(1): 87-119.

March, J. G. (1991). "Exploration and Exploitation in Organizational Learning." Organization Science **2**(1, Special Issue: Organizational Learning: Papers in Honor of (and by) James G. March): 71-87.

Moir, I. and A. Seabridge (2006). Military Avionics Systems. Chichester, England John Wiley & Sons.

Nickerson, J. A. and T. R. Zenger (2004). "A Knowledge-Based Theory of the Firm - The Problem-Solving Perspective." Organization Science **15**(6): 15.

Nobeoka, K. (1993). Multi-project management: strategy and organization in automobile product development, Massachusetts Institute of Technology, Sloan School of Management.

Nobeoka, K. and M. Cusumano (1994). Multi-Project Strategy and Market-Share Growth: The Benefits of Rapid Design Transfer in New Product Development, IMVP Working Papers. Cambridge, MA: The MIT Press.

Nonaka, I. (1994). "A Dynamic Theory of Organizational Knowledge Creation." Organization Science **5**(1): 14-37.

Nonaka, I. and H. Takeuchi (1995). The knowledge-creating company : how Japanese companies create the dynamics of innovation. New York, Oxford University Press.

Okhuysen, G. A. and K. M. Eisenhardt (2002). "Integrating Knowledge in Groups: How Formal Interventions Enable Flexibility." Organization Science **13**(4): 370-386.

Polanyi, M. (1966). The Tacit Dimension, Routledge & Kegan Paul Ltd.

Prencipe, A. (2000). "Breadth and depth of technological capabilities in CoPS: the case of the aircraft engine control system." Research Policy **29**(7): 895-911.

Prusak, L. (1996). "The Knowledge Advantage." Strategy & Leadership **24**(2): 6-8.

Purvis, R. L., V. Sambamurthy, et al. (2001). "The Assimilation of Knowledge Platforms in Organizations: An Empirical Investigation." Organization Science **12**(2): 117- 135.

Santos, F. M. and K. M. Eisenhardt (2005). "Organizational Boundaries and Theories of Organization." Organization Science **16**(5): 491-508.

Senge, P. (1994). The Fifth Discipline: The Art and Practice of the Learning Organization, Currency.

Simon, H. A. (1973). "Applying Information Technology to Organization Design." Public Administration Review **33**(3): 268-278.

Spender, J.-C. (1996). "Making Knowledge the Basis of a Dynamic Theory of the Firm." Strategic Management Journal **17**(Special Issue: Knowledge and the Firm. (Winter, 1996)): 45-62.

Spender, J. C. (1996). "Competitive advantage from tacit knowledge? Unpacking the concept and its strategic implications." Organizational Learning and Competitive Advantage: 56-73.

Star, S. L. (1989). The structure of ill-structured solutions: Boundary objects and heterogeneous distributed problem solving. Menlo Park, CA., M. Huhns and L. Gasser, eds.

Szulanski, G. (1996). "Exploring internal stickiness: Impediments to the transfer of best practice within the firm." Strategic Management Journal **17**(Winter 1996): 27-44.

Takeishi, A. (2001). "Bridging inter- and intra-firm boundaries: management of supplier involvement in automobile product development." Strategic Management Journal **22**(5): 403-437.

Takeishi, A. (2002). "Knowledge Partitioning in the Interfirm Division of Labor: The Case of Automotive Product Development." Organization Science **13**(3): 321-338.

Takeuchi, H. and I. Nonaka (2004). Hitotsubashi on knowledge management, John Wiley & Sons (Asia) Singapore.

Vincenti, W. G. (1990). What Engineers Know and how They Know it: Analytical Studies from Aeronautical History, Johns Hopkins University Press.

Von Hippel, E. (1994). ""Sticky Information" and the Locus of Problem Solving: Implications for Innovation." Management Science **40**(4): 429-439.

Womack, J. and D. Jones (1996). "Lean Thinking: Banish Waste and Create Wealth in Your Organisation." Rawson Associates, New York.

Womack, J. P., D. T. Jones, et al. (1991). The Machine that Changed the World: How Japan's Secret Weapon in the Global Auto Wars Will Revolutionize Western Industry, HarperPerennial.

Yang, J. (2005). "Knowledge integration and innovation: Securing new product advantage in high technology industry." Journal of High Technology Management Research **16**(1): 121-135.