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AN EXTENDED MODEL OF KNOWLEDGE-FLOW DYNAMICS

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ABSTRACT

The modern enterprise depends upon timely and effective flows of knowledge through its organizations for success. But knowledge is not evenly distributed through the enterprise, and a dearth of information systems is available to enable such timely and effective flows. Further, the few theoretical knowledge-flow models available have not yet been developed to a point where they can effectively inform the design of information systems and business processes to support knowledge flow in the enterprise. A survey of current practice shows that such system and process design is accomplished principally by trial and error, one of the least effective approaches known. The research described in this article builds upon and extends current theory about knowledge flow. It focuses in particular on investigating flow dynamics to inform the design of information systems and business processes to enhance the flow of knowledge through the enterprise. Leveraging the good understanding of flows in other domains, we strive to extend theory that can lead to "devices" of considerable utility in the enterprise knowledge domain. The result is a four-dimensional, dynamic model that can be used to classify and visualize a diversity of knowledge-flow patterns through the enterprise. These patterns can, in turn, be analyzed to inform the design of useful information systems and business processes. The implications of this dynamic model are explored and a number of hypotheses are generated to motivate and guide future research into the phenomenology of knowledge flow.

KEYWORDS: business process re-engineering, knowledge flow, knowledge management, knowledge transfer.

I. INTRODUCTION

Many scholars [e.g., Drucker 1995] assert that knowledge represents one of the very few sustainable sources of comparative advantage, and the practice of knowledge management (KM) takes the power of knowledge to the group, organization and even enterprise level [Davenport and Prusak 1998]. Within KM, current survey work identifies knowledge transfer as a key area in need of additional research, indicating that there are "large gaps in the body of knowledge in this area" [Alavi and Leidner 2001, p. 126]. If we accept that knowledge is an entity that *can be* transferred [cf. Brown and Duguid 1998], then familiarity with other transferable entities (e.g., electricity, fluids, manufactured items, cargo) leads us to conceptualize this phenomenon in terms of *flow*. We leverage our understanding of well-defined flows from both physical and organizational domains to help build theory to describe the phenomenology of knowledge flow.

The primary objective of knowledge flow is to enable the transfer of capability and expertise from where it resides to where it is needed—across time, space and organizations as necessary. The problem is, knowledge is not evenly distributed through the enterprise. The larger, more geographically-dispersed and time-critical an enterprise, the more that it depends on the timely and effective flow of knowledge through its organizations for success. Exacerbating this problem is the dearth of information systems available to enable such timely and effective flows.

Notwithstanding the many contemporary information systems labeled "KM tools" (e.g., groupware, Web portals, search engines) that are available and being employed in hopes of enhancing the flow of knowledge through many enterprises, few such tools even address knowledge as the focus or object of flow. Rather, nearly all contemporary information systems focus instead of the transfer of information and data, which are qualitatively different across numerous dimensions [cf. Davenport et al. 1998, Teece 1998]. Further, the few theoretical knowledge-flow models available [e.g., Dixon 2000, Nonaka 1994] have not yet been developed to a point where they can effectively inform the design of information systems and business processes to enable, automate and support knowledge flow in the enterprise. A survey of current practice [Nissen et al. 2000] shows that such system and process design is accomplished principally by trial and error, one of the least-effective design approaches known.

The research described in this article builds upon and extends current theory pertaining to knowledge flow and focuses, in particular, on investigating its dynamics to inform the design of information systems and business processes. Leveraging the good understanding of flows in physical (e.g., electronics, aerospace) and organizational (e.g., manufacturing, logistics) domains, in which many flow-enhancing devices (e.g., amplifiers, engines, assembly lines, distribution hubs) were developed and demonstrated, we extend theory that can lead to "devices" (e.g., knowledge amplifiers and engines) of comparable utility in the enterprise knowledge domain.

This article begins with background on knowledge flow (Section II). Section III describes our knowledge-flow model development through extension to existing theory, upon which we reflect to identify important research implications and propose a number of research hypotheses. The contribution of this work is summarized along with key conclusions to close the article.

II. BACKGROUND

This section draws heavily from Nissen et al. [2000] to summarize key background work pertaining to knowledge flow. The section begins with an overview of important concepts from the emerging knowledge management literature. Research to integrate re-engineering with knowledge management is then covered, after which we outline the theoretical underpinnings used to model knowledge-flow dynamics in this study.

KNOWLEDGE MANAGEMENT LITERATURE

For purposes of this article, four important concepts from the KM literature are summarized:

1. knowledge hierarchy,
2. information technology,
3. knowledge-based systems, and
4. knowledge management life cycle.

The corresponding discussion helps frame current thinking and activity in KM. It is specifically focused on concepts employed in this research.

KNOWLEDGE HIERARCHY

Many scholars [cf. Davenport and Prusak 1998, Nissen et al. 2000, von Krough et al. 2000] conceptualize a hierarchy of knowledge, information, and data. As illustrated in Figure 1, each level of the hierarchy builds on the one below. For example, data are required to produce information, but information involves more than just data (e.g., need to have the data in context).

Similarly, information is required to produce knowledge, but knowledge involves more than just information (e.g., it enables action). We operationalize the triangular shape of

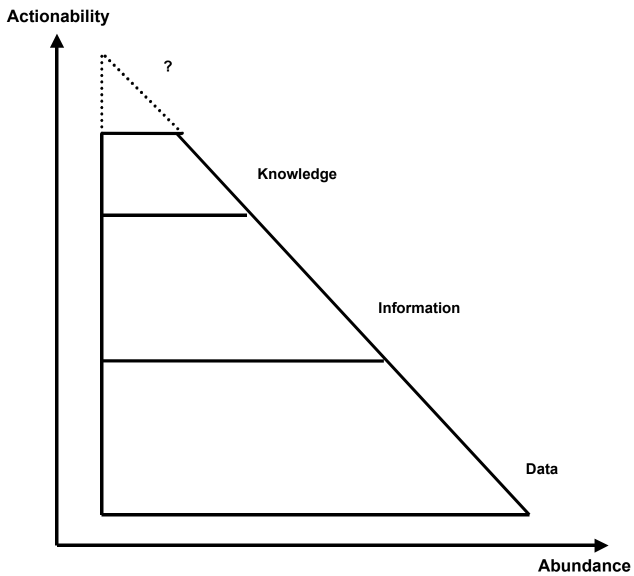

Figure 1. Knowledge Hierarchy

this hierarchy using two dimensions—abundance and actionability—to differentiate among the three constructs.

Briefly, data lie at the bottom level, with information in the middle and knowledge at the top. The broad base of the triangle reflects the abundance of data, with exponentially less information available than data and even fewer chunks of knowledge in any particular domain. Thus, the width of the triangle at each level reflects decreasing abundance in the progress from data to knowledge. The height of the triangle at each level reflects actionability (i.e., the ability to take appropriate action, such as a good decision or effective behavior). Converse to their abundance, data are not particularly powerful for supporting action, and information is more powerful than data. But knowledge supports action directly, hence its position near the top of the triangle.

This, notional view of the hierarchy is shared by many scholars, but certainly not all. For example, Tuomi [2000] argues for an inverted hierarchy, in which hierarchical relationships such as those outlined above are inverted to reflect data on the "top" and knowledge on the "bottom." His argument is that knowledge is required to establish a semantic structure to represent information, which in turn represents a prerequisite for creating data.

Perhaps this apparent contradiction can be resolved by introducing the concept *directionality* in terms of knowledge flow. As depicted in the context of knowledge transfer through Figure 2, the transferor of knowledge could indeed view the hierarchy as conceptualized by Tuomi—where knowledge is necessary to produce information, which in turn is necessary for creating data that is conveyed (e.g., via paper, network, speech, observable action). However, the receiver of knowledge would view the hierarchy in the opposite perspective outlined above—where data are placed into context to become information, and information that enables action becomes knowledge.

The dynamic aspect of knowledge associated with directional flow also represents an important part of Spiegler's [2000] alternative conceptualization, which focuses on transformations (e.g., data to information, information to knowledge). This alternative conceptualization also supports a double hierarchy, in which such transformations convert data to knowledge and vice versa. With the flow-directionality concept from above, these alternative models are not contradictory. The latter model also discusses a level "above" knowledge in the hierarchy termed *wisdom*, which also receives speculation in the trade press [cf. Angus 1998, Mullins 1999]. The present article does not attempt to address "wisdom management."

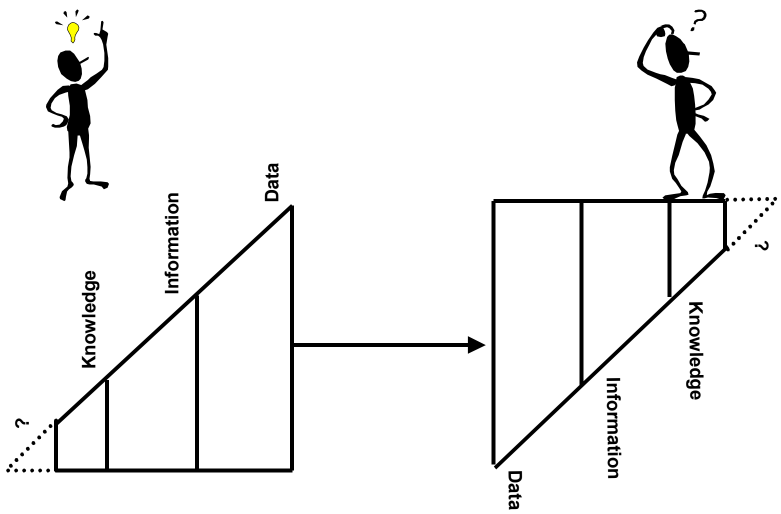

Figure 2. Knowledge Flow Directionality

INFORMATION TECHNOLOGY

Current information technology used to support KM is limited primarily to conventional database management systems (DBMS), data warehouses and data mining tools (DW/DM), intranets/extranets, portals and groupware [O'Leary 1998]. Arguably, just looking at the word "data" in the names of many "knowledge management tools" (e.g., DBMS, DW/DM), we are not even working at the level of information, much less knowledge. Although (esp. Web-based) Internet tools applied within and between organizations provide a common, machine-independent medium for the distribution and linkage of multimedia documents, current intranet and extranet applications focus principally on the management and distribution of information, not knowledge per se.

Along these same lines, groupware offers infrastructure support for knowledge work and enhances the environment in which knowledge artifacts are created and managed, but the flow of knowledge itself remains indirect. For example, groupware is widely noted as helpful in:

- the virtual office environment (e.g., when geographically-dispersed knowledge workers must collaborate remotely),
- provides networked tools such as shared, indexed and replicated document databases and discussion threads (e.g., Lotus Notes/Domino applications),
- shared "white boards,"
- joint document editing capabilities, and
- full-duplex, multimedia communication features.

These tools serve to mitigate collaboration losses that can arise when rich, face-to-face joint work is not practical or feasible. But supporting (even rich and remote) communication is not sufficient to guarantee knowledge flow.

KNOWLEDGE-BASED SYSTEMS

Construction and use of knowledge-based systems (KBS) can make knowledge explicit and its application direct. Key KBS technologies include applications such as:

- expert systems and intelligent agents,
- infrastructure and support tools such as ontologies, knowledgebases, inference engines, search algorithms, list and logic programming languages, and
- a variety of representational formalisms (e.g., rules, frames, scripts, cases, models, semantic networks).

Much deeper than just their names' sake, KBS are predicated on the capture, formalization and application of strong domain knowledge. The use of KBS for knowledge organization and distribution is well known, widespread, and now the subject of textbook application [cf. Russell and Norvig 1995, Turban and Aronson 2001].

Unlike the extant IT tools noted above, the substance of KBS is knowledge itself—not just information or data—and KBS are designed to interpret and apply represented knowledge directly. These capabilities and features make KBS distinct from most classes of IT applications presently employed for KM [cf. Smith and Farquhar 2000]. However, expert system development—through classic knowledge engineering—requires explicit capture and formalization of tacit knowledge possessed by experts. This is just the kind of tacit knowledge that researchers [e.g., Leonard and Sensiper 1998, p. 112] stress "underlies many competitive capabilities." However, such knowledge has long been known as being "hard to capture."

KNOWLEDGE MANAGEMENT LIFE CYCLE

Nissen et al. [2000] observe a sense of process flow or a life cycle associated with knowledge management. Integrating their survey of the literature [e.g., Despres and Chauvel 1999, Gartner Group 1999, Davenport and Prusak 1998, Nissen 1999], they synthesize an amalgamated KM life cycle model as outlined in Table 1. Notice that most of the four life cycle models begin with a "create" or "generate" phase; only the Nissen model begins with knowledge capture, an activity appearing in the *third* phase of the Gartner Group model. The second phase pertains to the organization, mapping or bundling of knowledge; Davenport and Prusak do not make specific reference to this organization phase from their model, but it is implied by their codify phase and appears very prominently in all the others.

Table 1. Knowledge Management Life Cycle Models
[Adapted from Nissen et al. 2000]

Model	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
Despres and Chauvel	Create	Map/ bundle	Store	Share/ transfer	Reuse	Evolve
Gartner Group	Create	Organize	Capture	Access	Use	
Davenport & Prusak	Generate		Codify	Transfer		
Nissen	Capture	Organize	Formalize	Distribute	Apply	
Amalgamated	Create	Organize	Formalize	Distribute	Apply	Evolve

Phase three uses different terms across the models, but they all address some mechanism for making knowledge formal or explicit. Likewise, the fourth phase uses different terms but addresses the ability to share or distribute knowledge in the enterprise. Three of the four models include a fifth phase for application or (re)use of knowledge for problem solving or decision making in the organization, but such application and (re)use is implied as an objective in all. Only the Despres and Chauvel model explicitly includes a sixth phase for knowledge evolution.

The Amalgamated Model integrates the key concepts and terms from the four life cycle models. Compare the steps proposed by Nissen (1999), for example, with the Amalgamated Model. Notice from Table 1 the Amalgamated life cycle model makes a distinction between knowledge creation (as proposed by Despres and Chauvel and Gartner Group) and its capture or formalization (i.e., Phase 3). Whereas knowledge creation involves discovery and the development of new knowledge, knowledge capture requires only that the knowledge be new to a particular individual or organization, and formalization involves the conversion of existing knowledge from tacit to explicit form. The Amalgamated Model therefore seems more complete with its beginning at the creation step. Similarly, the Amalgamated Model also adopts the evolution step from Despres and Chauvel.

Drawing further from this research on life cycle models, Nissen et al. note that coverage of existing information systems and business practices across these life cycle phases is patchy. For example, numerous systems and practices are identified from the literature, but they support only three of the six life cycle phases: knowledge organization, formalization and distribution. Alternatively, relatively few counterpart systems and practices are found to correspond with the other three phases: knowledge application, evolution and creation. We thus observe a relative abundance of systems and practices available to support three of the phases of the KM life cycle and a dearth for the other three phases.

RE-ENGINEERING AND KNOWLEDGE MANAGEMENT INTEGRATION

Substantial integration of knowledge management with re-engineering is observed in current practice, as companies realize the direct connection between KM and knowledge-work process innovation [Davenport et al. 1998]. In their study of more than thirty KM efforts in industry, Davenport et al. [1996] note the practice is "fundamentally change management projects." Emerging theory of knowledge creation and management has a dynamic, distinctly process-oriented flavor [see esp. Nonaka 1994]. Ruggles [1998] goes so far as to suggest a primary objective of practice is to assess the impact of KM as a process, fundamentally a proposition of re-engineering.

However, as learned through the painful, expensive and failure-prone "first wave" of re-engineering [Cypress 1994], simply inserting IT into a process in no way guarantees performance improvement. Indeed, many otherwise successful and effective firms experience process *degradation* as the result of re-engineering [cf. Caron et al. 1994, Hammer and Champy, 1993]. This point is underscored by Hammer [1990], whom colorfully refers to such practice as "automating the mess" (e.g., making a broken process simply operate—broken—faster).

Drawing on Leavitt [1965] and others [cf. Davenport 1993, Nissen 1998], new IT needs to be integrated with the design of the process it supports. That is, the organization, people, procedures, culture and other key factors need to be considered in addition to technology. Given that many KM projects now revolve around IT implementation (e.g., intranets/extranets, Web portals, groupware; [cf. Nissen et al. 2000]), re-engineering and knowledge management even appear to be sharing some of the same mistakes.

Building upon this research, we begin to characterize a powerful interaction between the flow of work (i.e., workflow; [cf. Georgakopoulos et al. 1995]) and the flow of knowledge (i.e., knowledge flow) in an enterprise. Following Oxendine and Nissen [2001], we refer to these flows as *horizontal processes* and *vertical processes*, as conceptualized in Figure 3. Briefly, the two horizontal directed graphs in the figure delineate separate examples of a work process (e.g., steps 1 – 6 as performed at different points in time, space, organization). The graph at the top of Figure 3 represents one particular example (e.g., performed at a specific point in time, location, organization) of this notional process, and the graph at the bottom represents a *different* example (e.g., performed at a separate point in time, location, organization).

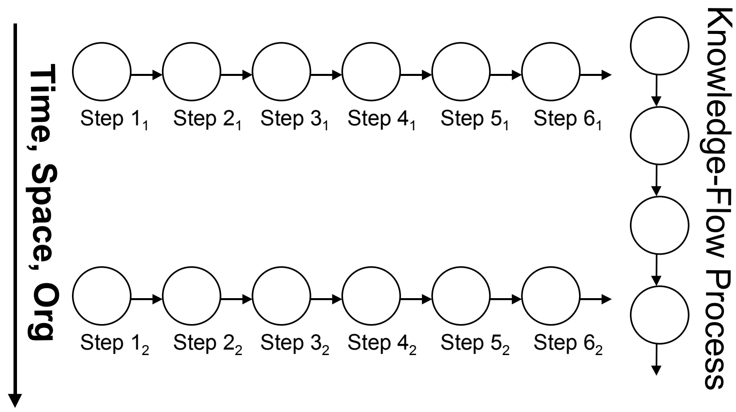

Figure 3. Horizontal and Vertical Processes

Both horizontal graphs represent the flow of *work* through the enterprise. The vertical graph represents a complementary set of processes responsible for the flow of *knowledge*. As noted in Section I, knowledge is not evenly distributed through the enterprise, yet enterprise performance is dependent upon consistency and effectiveness *across* various workflows. The associated knowledge (e.g., process procedures, best practices, tool selection, and usage) flow across time, space and organizations. Such cross-process activities are seen as driving the flow of knowledge—as opposed to the flow of work—through the enterprise. Indeed, Nissen and Espino [2000] identify seven vertical processes (e.g., training, personnel assignment, IT support) that interact in a complex manner that is not reflected by the simple, linear flow depicted in the figure. It is upon these vertical process flows that we concentrate in this research.

CURRENT KNOWLEDGE-FLOW THEORY

One of the best-known theoretical treatments of knowledge flow to date stems from Nonaka [1994] in the context of organizational learning. This work outlines two dimensions for knowledge:

- *epistemological*, and
- *ontological*.

The epistemological dimension depicts a binary contrast between explicit and tacit knowledge. Explicit knowledge can be formalized through artifacts such as books, letters, manuals, standard operating procedures, and instructions, whereas tacit knowledge pertains more to understanding and expertise contained within people's minds. The ontological dimension depicts knowledge that is shared with others in groups or larger aggregations of people across the organization. Although this aggregation of organizational units appears arbitrary, in the enterprise context, it could clearly apply to small teams, work groups, formal departments, divisions, business units, firms and even business alliances or networks.

As shown in Figure 4, Nonaka uses the interaction between these dimensions as the principal means for describing knowledge flow. This flow is roughly characterized through four steps.

First, Nonaka asserts that new knowledge is created only by individuals in the organization and is necessarily tacit in nature. The first flow of knowledge is then theorized to occur through a process termed socialization, which denotes members of a team sharing experiences and perspectives, much as one anticipates through communities of practice.

Socialization flow is noted as vector 1 in Figure 4 and corresponds to tacit knowledge (i.e., along the epistemological dimension) flowing from the individual to the group level (i.e., along the ontological dimension).

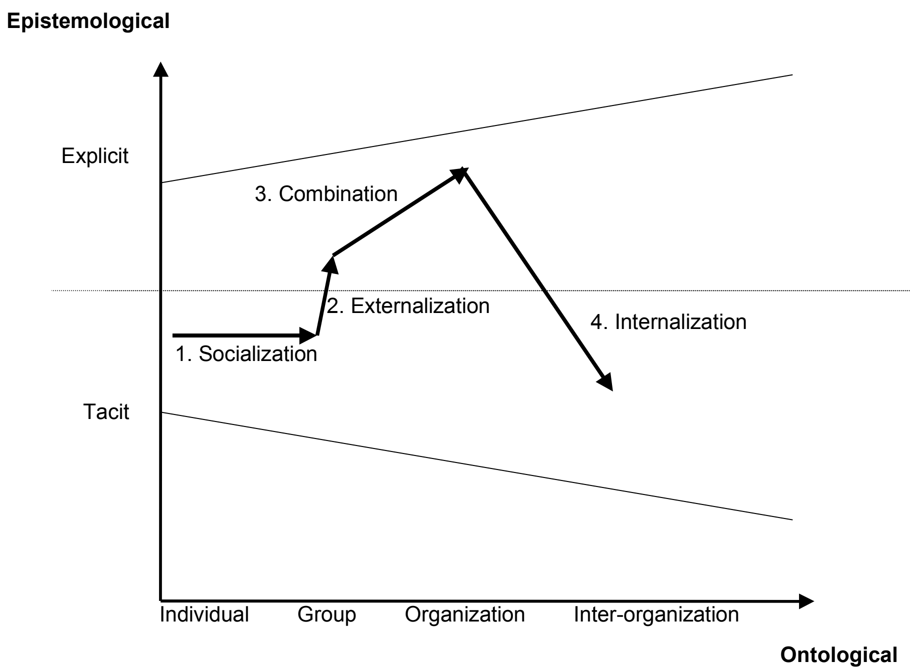

Figure 4. Nonaka Knowledge Flow Theory
[Adapted from Nonaka 1994]

The second flow of knowledge (vector 2) is theorized to occur through a process termed externalization, which denotes the use of metaphors through dialog that leads to articulation of tacit knowledge and its subsequent formalization to make it concrete and explicit.

The third flow of knowledge (vector 3) is theorized to occur through a process termed combination. Combination denotes coordination between different groups in the organization—along with documentation of existing knowledge—to combine new, intra-team concepts with other, explicit knowledge in the organization.

The fourth flow of knowledge (vector 4) is theorized to occur through a process termed internalization. Internalization denotes diverse members in the organization applying the combined knowledge from above—often through trial and error—and in turn translating such knowledge into tacit form at the organization level.

III. KNOWLEDGE-FLOW DYNAMICS

This section begins by building upon Nonaka's theory to conceptualize an extended model of knowledge-flow dynamics. This extended model is intended to help researchers to understand better the phenomenology of knowledge flow, and as a theoretical contribution, it may help to describe better and explain how knowledge flows through the enterprise.

BUILDING UPON CURRENT THEORY

The first step toward building on current knowledge-flow theory is to augment Nonaka's two-dimensional framework by incorporating a third dimension, the KM life cycle. We operationalize the construct using the life-cycle stages from the Amalgamated Model that was presented in Table 1. Further, because the concept of flow is inherently dynamic, we extend this framework by incorporating time as a key, fourth dimension. Such augmented dimensionality preserves—and indeed subsumes—Nonaka's two-dimensional framework and provides the basis for a richer model. This richer model may enhance our descriptive and explanatory power in terms of understanding the knowledge-flow phenomenon.

The second step toward building on current knowledge-flow theory pertains to the epistemological dimension (Section II) that includes only binary states (i.e., tacit, explicit). In contrast, we propose that knowledge fills a continuum between the tacit and explicit endpoints. Instead of a simple contrast between explicit and tacit knowledge, a continuum allows tracing knowledge as it flows through a continuous *range* of explicitness. A continuous dimension makes for a richer model than—and indeed subsumes—one with only two binary states.

This same rationale can be applied to the ontological dimension (Section II). It supports only a few, granular states (e.g., individual, group, organization). In contrast, we propose that knowledge may fill a continuum along the dimension characterized by how many people are reached by the knowledge (e.g., at a particular level of explicitness, life cycle phase). Tracing knowledge flows across a continuous dimension similarly makes for a richer model than—and indeed subsumes—one with only a few discrete states.

A third step toward theory building stems from the differentiation between vertical processes and their horizontal-process counterparts (Section II) in terms of enabling knowledge flows versus work flows, respectively. Such differentiation is simply absent from current theory. But it highlights an important, cross-process focus of knowledge flow, and it may help explain the mechanics associated with prior theory (e.g., Nonaka's concepts of socialization, externalization, combination). Moving from description to explanation represents an important aspect of theory building [Bacharach 1989].

AN EXTENDED MODEL OF KNOWLEDGE FLOW

The theory building in the previous subsection provides the basis from which to develop an extended model of the knowledge-flow phenomenon. In Figure 5[1], we note a few, notional, knowledge-flow vectors for illustrating and classifying various dynamic patterns of knowledge as it flows through the enterprise. For example, the simple, linear flow labeled "Policies and Procedures" depicts the manner in which most enterprises inform and train employees through the use of policies and procedures: explicit documents and guidelines that individuals in the organization are expected to memorize, refer to and observe. As another example, the cyclical flow of knowledge described by the amalgamated KM life cycle model (Table 1), shown in the figure, reflects a more-complex dynamic than its simple, linear counterpart. This flow describes a cycle of knowledge creation, distribution and evolution within a workgroup, for example.

Further, Nonaka's dynamic theory of knowledge flow can also be described in this space by the curvilinear vector sequence corresponding to the processes labeled "create," "socialize," "externalize," "combine" and "internalize," respectively. Thus, our model subsumes the one proposed by Nonaka and shows a somewhat-complex dynamic as knowledge flows along the life cycle. Moreover, examination of this space suggests also including the refine vector, which is not part of Nonaka's theory but represents a key element of the empirically-derived, Amalgamated Model (e.g., the key to knowledge evolution). Clearly, a great many other flows and patterns can be shown in this manner. Preliminary results from field work [cf. Nissen 2001 for research agenda] suggest that this vector-space approach to depicting and visualizing knowledge flows can be very useful for empirical investigation into the phenomenology of knowledge flow.

To complete our model development, we incorporate the *time* dimension into the model. Because static displays such as the graph presented in Figure 5 are difficult to visualize in more than three dimensions, we do not attempt to show all four dimensions at once. Rather, we

[1] Because Nonaka's terminology for the dimensions reflected in Figure 4 can lead to confusion (e.g., with respect to use of the terms *epistemological* and *ontological*), we substitute the term *explicitness* for *epistemological* and *reach* for *ontological* in Figure 5.

substitute the dimension *time* for its *life cycle* counterpart in Figure 6 to characterize the order-of-magnitude differences in flow times associated with various kinds of knowledge.

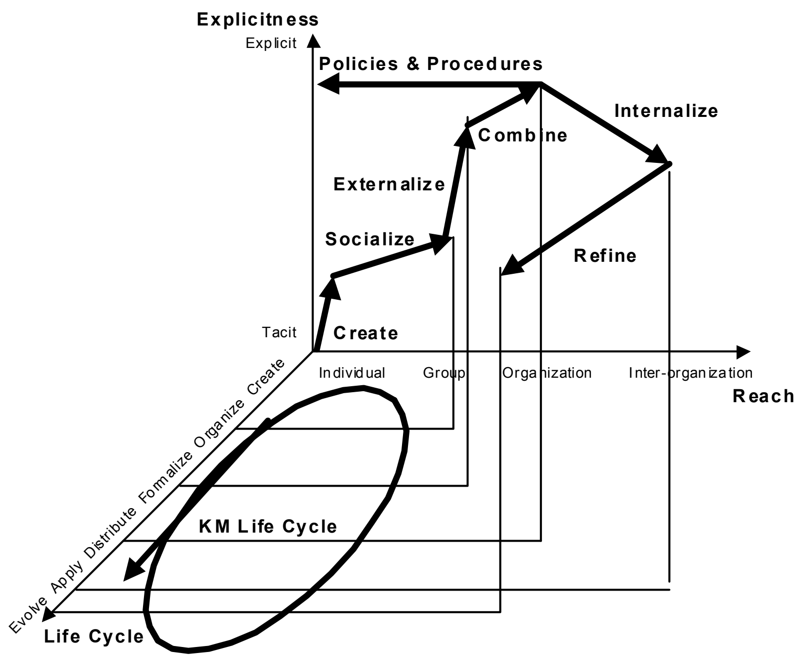

Figure 5. Extended Model with Knowledge Flows

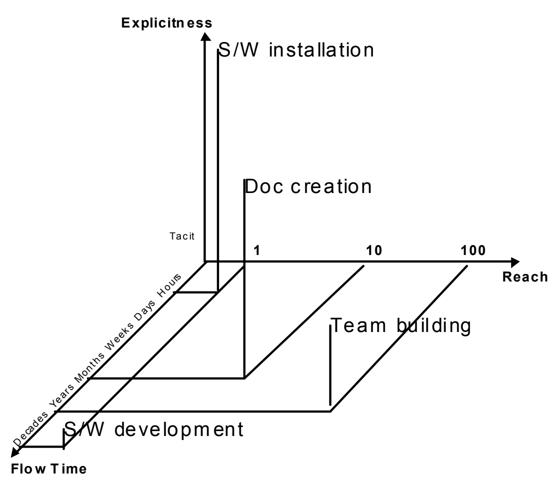

Figure 6. Knowledge Flows with Time Dimension

For example, if we take some highly explicit knowledge—say a printed document describing how to install a major software application on a desktop personal computer—then this flow of knowledge can conceivably be completed in a matter of hours. A computer literate person needs only to read the instructions before being able to install the software effectively. We plot this first example of knowledge flow (i.e., "S/W installation") in Figure 6, which delineates its three-dimensional classification as:

- highly-explicit knowledge,
- involving only one person in terms of reach,
- with flow time on the order of hours.

This example distinguishes between the flow of work (i.e., installing software) and the complementary flow of knowledge (i.e., understanding installation instructions) that enables such work to be done. Thus, in diagrams such as Figure 6, we explicitly define the kinds of *vertical processes* (i.e., knowledge flows) that drive knowledge required to perform horizontal processes (i.e., workflows).

As another instance, take this same document and consider the flow associated with its creation. Presumably, the authors of a software-installation document would be knowledgeable about the corresponding software application, as well as how to write effective installation instructions. Depending on how extensive and complex an application is, understanding its installation idiosyncrasies could take several months, even though writing the instructions themselves could probably be accomplished in a matter of weeks. Here again, we differentiate between the flow of work (i.e., writing installation instructions; requiring weeks) and the corresponding flow of knowledge (i.e., understanding software-installation idiosyncrasies; requiring months) that enables such work to be performed effectively.

Notice also, the flow time associated with knowledge required to develop the installation document (e.g., months) is one or more orders of magnitude longer than the complementary flow time associated with an individual understanding how to install the software (e.g., hours). We plot this second knowledge flow (i.e., "Doc creation") in the figure, as it represents moderately-explicit knowledge (e.g., some tacit knowledge is required to understand the software), involving a group of people (e.g., 10) in terms of reach (e.g., assuming that people from several different organizations are required to develop the instructions), and requiring months for the knowledge to complete its flow.

As a third instance, consider development of the software application itself. Again depending upon the extensiveness and complexity, a comparatively-long period of time could be required for people to acquire the levels of software-engineering knowledge and experience necessary for its development. Consider that the software architects and engineers must complete several years of college and acquire numerous years of software experience before developing the knowledge and experience required to develop a major software product. In some cases, a decade or more may be required for the requisite knowledge to complete its flow and enable someone to develop the software application. We plot this third instance (i.e., "S/W development") in Figure 6.The knowledge required to develop software is relatively tacit compared to the knowledge required to write the installation manual. We show this knowledge flow at the individual level.

To develop a major software application such as discussed in this example, a large number of individual software architects and engineers must learn to work effectively in groups and organizations. This team-building knowledge flow is depicted (i.e., "Team building") in the figure, concerning relatively-tacit knowledge, involving many people (e.g., 100) in a relatively-large organization in terms of reach, and conceivably requiring years to complete its flow. Once again, we distinguish between the flow of work to develop a software application and the complementary flow of knowledge (e.g., software engineering, team-building) that drives it.

Further, if we trace the flow of knowledge through the life cycle shown in Figure 6, we develop a composite illustration of its dynamics. For example, the knowledge begins with education and experience qualifying a person to develop software (i.e., "S/W development"), which is highly tacit and requires a decade or more to flow for a given individual. The next flow involves building an effective team to develop the software (i.e., "Team building"), which we delineate as tacit and involving many people over years. The knowledge required to write and test the installation instructions is more explicit, requiring fewer people and less time to acquire (i.e., "Doc creation"), and the flow of knowledge associated with reading the instruction and installing the software is labeled "S/W installation" (i.e., highly-explicit, individual, hours). We use the broad arrows in Figure 7 to show the composite knowledge-flow vector as it crosses these four life-cycle phases.

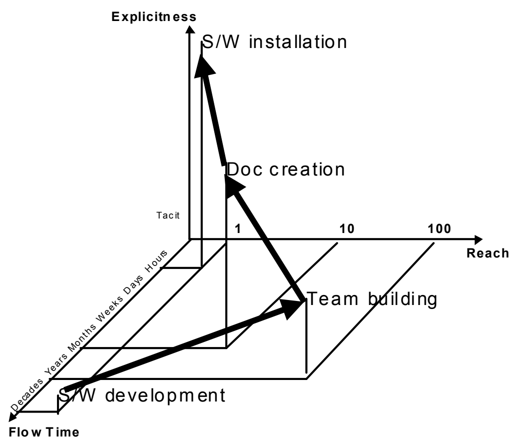

Figure 7. Composite Knowledge Flow

In this section we built on existing theory to extend a model of knowledge-flow dynamics. We illustrated the use of this model by classifying and describing several knowledge-flow vectors associated with the development and installation of a major software application. On the surface, this extended model appears to be considerably richer and more-explanatory than the prior theoretical counterparts upon which it builds, and it may prove to be useful for understanding the phenomenology of knowledge flow better. Such better understanding, we argue, is important for informing the design of useful information systems and business processes to enhance the flow of knowledge in the enterprise. But, as a theoretical proposition, this assertion remains to be examined and verified empirically.

IV. RESEARCH IMPLICATIONS AND HYPOTHESES

So what are the implications of this extended model of knowledge-flow dynamics, and what new research hypotheses can we develop to help motivate and guide future research? In this section, we discuss three such implications and propose corresponding hypotheses.

FIRST IMPLICATION

The first implication is associated with the increased dimensionality of the extended knowledge-flow model. This extension provides a richer model and subsumes the prior work of Nonaka and others. It also offers a multidimensional framework for attempting to classify various knowledge flows. We can further use these knowledge flows to help characterize, visualize, and compare the diversity of flows expected to exist in modern enterprises. Further, these dimensions may prove useful to identify various knowledge-flow patterns that can be observed or otherwise inferred through empirical work. With such patterns identified, we may be able to then organize and correlate them, perhaps developing a taxonomy. Three research hypotheses relate directly to this increased dimensionality.

Hypothesis 1. The dimensions associated with the Extended Knowledge-Flow Model can be used to classify and plot a variety of knowledge flows.

Hypothesis 2. The Extended Knowledge-Flow Model can be used to identify and discriminate between distinct knowledge-flow patterns.

Hypothesis 3. Distinct knowledge-flow patterns can be matched with the IT most appropriate for their automation and support.

SECOND IMPLICATION

The second implication is associated with the vertical processes posited to drive the flow of knowledge. This insight into the mechanics of knowledge flow is useful for contrasting the flow of work through an enterprise with the complementary flow of knowledge. Further, we can consider that the time frames associated with some knowledge flows may be orders of magnitude longer than those associated with the corresponding workflows, as well as other flows such as information and data through the enterprise. Indeed, even flow times associated with alternative knowledge flows may differ by one or more orders of magnitude. Three research hypotheses relate directly to the vertical processes.

Hypothesis 4. Vertical processes can be identified and related to complementary workflows.

Hypothesis 5. Specific vertical processes drive distinct knowledge-flow patterns.

Hypothesis 6. Distinct knowledge-flow patterns can be matched with their corresponding vertical processes in terms of problem diagnosis and redesign.

THIRD IMPLICATION

The third implication is associated more generally with the phenomenology of knowledge flow. In terms of theory development, the *knowledge flow* concept may prove useful to describe the dynamics of knowledge management, and models to describe and explain the mechanics of how knowledge flows in the enterprise may be developed to expand our understanding of this phenomenon. If we are ultimately interested in developing useful “devices” to automate and support enterprise knowledge flows, then one can argue that we will first need to understand the associated mechanics. Otherwise, we must continue to rely on the kinds of trial-and-error design approaches being employed today. In domains such as electronics, aerospace, manufacturing and logistics, an understanding of the underlying flow mechanics represents a prerequisite to developing useful devices (e.g., amplifiers, engines, assembly lines, distribution hubs) to enhance and optimize such flows. We can foresee no difference in terms of the enhancement and optimization of knowledge flow.

V. CONCLUSION

The modern enterprise depends upon timely and effective flows of knowledge through its organizations for success. But knowledge is not evenly distributed through the enterprise, and a dearth of information systems is available to enable timely and effective flows. Further, the few theoretical knowledge-flow models available have not yet been developed to a point where they can effectively inform the design of information systems and business processes to support knowledge flow in the enterprise. A survey of current practice shows that such system and process design is accomplished principally by trial and error, one of the least effective approaches known.

The research described in this article builds upon and extends current theory pertaining to knowledge flow. It focuses in particular on investigating its dynamics to inform the design of information systems and business processes to enhance the flow of knowledge through the enterprise. Leveraging the good understanding of flows in other domains, we extend the theory that can lead to "devices" of considerable utility in the enterprise knowledge domain. The result is a four-dimensional, dynamic model that can be used to classify and visualize a diversity of knowledge-flow patterns through the enterprise. The patterns can, in turn, be analyzed to inform the design of useful information systems and business processes.

This extended, dynamic model makes a theoretical contribution by enriching our descriptive capability through increased dimensionality, and it increases our explanatory capability by delineating some mechanics associated with the flow of knowledge. Moreover, by differentiating between flows of knowledge and their complementary flows of work through the enterprise, we identify an important dynamic in terms of organizational capability. Further, we explored the implications of this dynamic model and generated a number of hypotheses to help motivate and guide future research into the phenomenology of knowledge flow. We look forward to contributing to such future phenomenological research.

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