# A qualitative exploration of entrepreneurial knowledge transfers

Alan T. Burns, William Acar and Pratim Datta

Alan T. Burns is the Program Chair, Business Department, Argosy University, Chicago, Ilinois, USA. William Acar is Professor and Pratim Datta is Assistant Professor of Information systems, both at the Graduate School of Management, Kent State University, Kent, Ohio, USA.

**Abstract**

**Purpose** – *This research seeks to explore the transfer and sharing of knowledge in entrepreneurial product development (EPD).*

**Design/methodology/approach** – *The effects of organizational complexity and of the temporal* locus *of learning on knowledge sharing are closely examined through a qualitative case study of four projects in a mid-size manufacturing firm.*

**Findings** – *Distinguishing between the prior and resulting shared knowledge, this paper uses case studies to establish the importance of learning-before-doing over learning-by-doing under conditions of entrepreneurial resource constraints.*

**Research limitations/implications** – *This paper revisits and extends the Hoopes and Postrel knowledge integration framework to include the mediating effects of organizational complexity and timing of learning on EPD performance in technology-based firms.*

**Practical implications** – *In order to better capture the impact of knowledge sharing on EPD, the paper also develops a method for measuring knowledge transfer directly in terms of three knowledge dimensions: depth, scope, and action.*

**Originality/value** – *The paper revisits and advances the conversation on knowledge sharing to highlight the importance of learning before doing in (entrepreneurial) firms facing resource constraints, where pure reliance on "on the job learning" may impede efficiencies and delay the absorption of knowledge for effective collaboration, integration and gains.*

**Keywords** *Knowledge management, Product development, Innovation, Entrepreneurialism*

**Paper type** *Research paper*

## Introduction

Knowledge is a core entrepreneurial asset. Entrepreneurs often try to create a differential niche by virtue of process innovation, a product of knowledge combination, expansion or reframing as categorized by Tsoukas (2009). Indeed, in a competitive market economy, entrepreneurs' ability to develop, transfer and manage knowledge constitutes the lifeblood of product development and manufacturing operations. Increasingly, researchers are exploring how knowledge is transferred across diverse specializations in an entrepreneurial firm, and how this knowledge can effectively be documented in the design and commercialization of technology for subsequent dissemination (Barr *et al.*, 2009).

Underlying this qualitative study is the age-old issue, revived in the mid-1990s by Nass (1994), of the respective roles of general knowledge and specific skills as the foundations on which to build technical know-how and product development. Investigation of this transformation of specialized knowledge into shared knowledge is becoming crucial for both research and practice. Patterns of shared knowledge constitute integrative practices that yield competitive advantage according to the resource-based view of the firm, since they cannot be purchased, transferred or developed easily (Hoopes *et al.*, 2003).

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This study offers a realistic exploration into the organic model, particularly some overlooked limitations of certain knowledge-sharing schemes. In investigating the phenomenon of knowledge sharing in entrepreneurial product development (EPD), the paper pays particular attention to the members' levels of knowledge as a prelude to knowledge sharing. While most research efforts have concentrated on understanding knowledge sharing from an organic perspective, the importance of knowledge levels in knowledge sharing has received little scrutiny. Yet, levels of knowledge are a core parameter in knowledge sharing. For example, in studying 1,550 alliances in 78 firms, Zhang and Baden-Fuller (2009) found that, although broad knowledge promoted firms to share knowledge, those with deep knowledge in specialized technological fields often felt prevented from sharing knowledge because of fear of information leakage.

Firms embody members with a wide variety of knowledge at various levels of specialization and diversity. While superficial knowledge can be easily transferred and shared, deep knowledge is more difficult to share (Datta, 2007). Similarly, sharing knowledge requires certain absorptive capacities on the part of the receiver. A receiver may be able to absorb knowledge at certain levels but may not be able to absorb knowledge at some other levels. After all, the ability to absorb knowledge requires a dynamic capacity to understand and assimilate knowledge for successful knowledge transfer (Lichtenthaler and Lichtenthaler, 2009). Thus, knowledge transfers and knowledge sharing remain incomplete without accommodating the levels of knowledge of the members involved in the task of knowledge sharing.

This paper scopes entrepreneurial knowledge transfers and knowledge sharing in the context of the series of organized activities supporting EPD. EPD is an appropriate context for knowledge and human capital management since it represents one of the few formal activities facilitating guided, purposeful learning across the entrepreneurial organization. Vaghely and Julien (2010) confirm that entrepreneurs perform boundary-spanning roles as knowledge creation activists who both reinforce interpersonal relationships and lubricate communications throughout the firm.

For the entrepreneur, developing and transferring knowledge for better performance in product development requires a concerted effort across business processes. Even non-technical processes such as customer relationship management are made possible by the marshalling of knowledge. Across industries, pivotal knowledge is generated by highly specialized entities whose expertise lies in different areas. In an entrepreneurial arena facing increasing resource constraints, knowledge workers must not only be cognizant of their specific expertise, but also be able to synthesize and transfer their knowledge to other groups. The simplistic view that increasing communication alone might suffice for success fails to recognize the fundamental organizational paradox that firms seeking effectiveness through superficial coordination do so at the cost of efficiency derived from specialization. More plausibly, entrepreneurial knowledge transformation and sharing involve complex integrative practices prior to yielding knowledge-based competitive advantages. Therefore, the paper asks: how can entrepreneurs effectively transform and share specialized knowledge for EPD within their firms?

Central to EPD is the notion of organizational learning. Innovations, particularly product development-related innovations, play an essential role in creating knowledge and sparking organizational learning (Datta, 2007). Hitt *et al.* (2000) state there are only two real types of organizational learning, both prominent in EPD:

1. acquisitive learning is the acquiring and internalizing of external knowledge outside the boundaries (the innovation or adoption stage); and
2. experimental learning is the result of active experimentation by members who acquire new knowledge distinctive to the organization (the development and transfer stage).

The literature (e.g., Pisano, 1996; Hatch and Dyer, 2004) reflects this distinction as a contrast between two distinct types of knowledge and learning. Advocates of learning before doing emphasize *a priori* conceptual knowledge, namely in the research laboratory. Learning *by*

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doing takes place in the production environment and emphasizes procedural knowledge. While both types are pivotal to the EPD process, the recent emphasis has been shifting to learning by doing, (e.g., Spender, 1996; Thomke and Reinertsen, 1998; Thomke, 2001; von Hippel and Tyre, 1995; Terwiesch and Böhn, 2001). Whether this trend is helpful to knowledge workers is one of the questions investigated in the present study.

Research has offered compelling evidence that product development performance is influenced by careful integration more than routine specialization (Adler, 1995; Allen, 1986; Clark and Fujimoto, 1991; Henderson and Clark, 1990; Iansiti, 1995; Leonard-Barton, 1992; von Hippel and Tyre, 1995). Summing up the trend, Hoopes and Postrel (1999) posited that integration creates patterns of shared knowledge that can overcome information- and knowledge-sharing deficiencies in overly specialized organizations. Building on this technology-transfer research stream, this qualitative case study explores how timing of knowledge sharing and structural complexity affect knowledge transfer in EPD projects, and thus their influence on product development performance. The proposed knowledge transfer scheme is informed by Hoopes and Postrel’s framework and examined in light of four complementary case studies.

The paper is organized as follows. Centrally relevant to our discussion are themes of knowledge depth, scope and action. Knowledge depth refers to the level of expertise of an entity in being able to analyze a given problem with existing data (Fiol, 1995). Knowledge scope is the breadth of specialized knowledge that a project draws on (Grant, 1996). Knowledge action is the pragmatics of making knowledge actionable through its application (Datta, 2007). To underpin EPD in organizational learning, the paper proposes a model making more explicit the timing of knowledge transfer and of organizational complexity, and then moves to tracing these concepts in the context of four projects. Specifically, the paper examines the role of knowledge sharing in achieving performance, and proposes a method for measuring knowledge depth to examine the extent of knowledge transfers in EPD. Empirically, this study is thus informed by the contrasting of four qualitative case studies drawn from a mid-size enterprise in the manufacturing sector. The paper ends with a discussion of the research along with its implications and limitations.

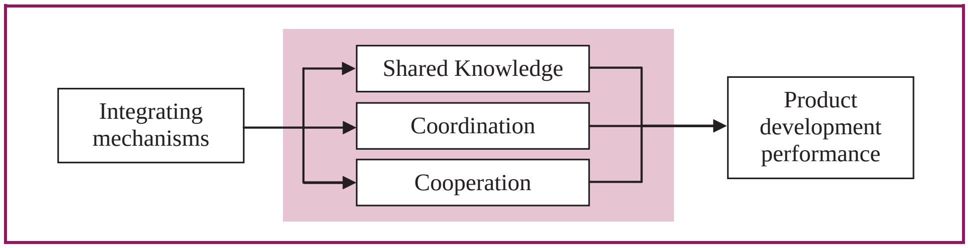
## Background

### *The framework of Hoopes and Postrel*

A decade earlier, Hoopes and Postrel (1999) proposed a framework (henceforth referred to as the H&P framework) delineating the effect of integration mechanisms on product development performance. Their model suggests integrative mechanisms promote product development success through channels of shared knowledge, coordination and cooperation (see Figure 1). The distinction between the channels is important because it points to different entrepreneurial directives that can guide EPD operations.

In the H&P framework, shared knowledge refers to how the entrepreneurial firm uses and distributes its knowledge within the firm and includes facts, concepts and propositions which are understood simultaneously by multiple agents. Coordination is concerned with how employees and subunits synchronize their actions within a firm for proper allocation of

**Figure 1** The Hoopes-Postrel model




scarce development resources, and cooperation refers to how employees balance their actions between a regard for their own personal interests and the interests of the firm.

The H&P framework commences our understanding of the role knowledge plays in EPD, but a formidable research challenge remains, due to the existence of cognitive gaps according to Jablokow and Booth (2006). The paper focuses on three challenges ahead, cumulative in difficulty:

1. measuring currently shared knowledge;
2. understanding the formation of new shared knowledge; and
3. investigating its effects on product development.

Since knowledge metrics are scarce, it would be difficult to measure the gap between existing and requisite knowledge for an EPD project. Drawing boundaries around what component of knowledge is considered ''shared'' is even more problematic. Finally, it would be necessary to somehow correlate these shared knowledge patterns with decisions made in the project, and somehow measure their effect on performance[1].

### *Learning in product development*

This paper views EPD as an instantiation of product development research, a horizontal organizational function superimposed on a layer of knowledge transfer within an organization. Conceptually, knowledge transfer can be viewed as iterating between only two modes, replication and adaptation (Williams, 2007); but temporally, EPD comprises three distinct stages: conceptualization, development and production. A large corpus of previous research emphasizes the two end stages of EPD, but our current focus is on the intermediate, more difficult to model stage that has received less scrutiny (Adler and Clark, 1991). The intermediate stage involves some form of development and production ramp-up (Terwiesch and Böhn, 2001). Production ramp-up is clearly the period between the end of development and full capacity production (Terwiesch and Böhn, 2001). It is worth noting that, for us, development (in our case, EPD) includes activities such as concept development work, feasibility testing, product design and component development process design (Takeuchi and Nonaka, 1986).

During early stages of development, learning is achieved primarily through experimentation, where EPD is a form of technical problem solving. Experiments are conducted to determine an unknown solution space of process parameters that optimize or satisfy a set of processing objectives (Pisano, 1996; von Hippel and Tyre, 1995). Learning, as acquisition of new knowledge, is achieved by experimentation (both physical and conceptual) providing continuous feedback on gaps in process performance. The latter stages are characterized by a shift away from controlled, laboratory experimentation toward pilot and full-scale production. Here, the learning burden shifts from R&D to production workers, who learn through ''doing'' or using activities.

For obvious reasons, the issue of learning-by-doing has been of great interest to researchers as much as to practitioners. Although it has been well stated (Arrow, 1962), the process by which doing contributes to gains in learning is not quite clear. Several authors have investigated the ''doing'' and ''using'' parts of learning. von Hippel and Tyre (1995) explore how problems are diagnosed through using upon introduction of new equipment to the factory floor. Tyre and Orlikowski (1994) describe the episodic and discontinuous process of learning, occurring just after introduction of new technology into production. After initial implementation, learning gives way to a behavioral tendency toward routinization.

Other, more traditional models describe learning as knowledge transfer from a source (R&D) to a recipient (production). Most are anchored in communication theory (Shannon and Weaver, 1949). The authors subscribe to Szulanski's (2000) description of knowledge transfer extended beyond mere transmission to a process of reconstruction where the organization recreates a complex, causally ambiguous set of routines in a new setting. His four stages of initiation, implementation, ramp-up and integration do match the stages of a typical product development cycle. It should be recognized that these models imply the traditionally opposite view of learning as necessarily having taken place before doing. Thus there is on-going controversy in the research literature on the optimal timing of knowledge transfer.

This controversy is increasing in sophistication but remains far from a clear resolution. For instance Adler and Clark (1991) develop a model of first-order learning (adaptive effects, a result of normal production activity) and second-order learning effects (the result of major process revisions such as training or engineering changes). Levin (2000) studies the effects of learning on product quality and automobile reliability. According to him, quality improvements are a function of the intensity of ''off-line'' activities involving transfer of external knowledge, not on the accumulation of production experience. Similarly, Purser *et al.* (1992) find learning is enabled by deliberations, namely patterns of reflection and communication exchange. This paper contributes to this important research debate on the timing of learning by means of a case study, a real-life study based on extending the H&P framework beyond the analysis of glitches in EPD activities.

## A proposed theoretical framework

### *Potential extensions of the H&P model*

Accounting for these research findings and other theoretical perspectives, the authors envision the eventual emergence of an integrative theoretical framework for entrepreneurial knowledge and product development. The framework potentially emerging from the literature is the expansion of H&P's model (Figure 2). It is viewed as adopting the central part of Figure 1 and expands its two ''wings''.

*The right wing.* The right wing of the H&P framework deals with product development performance, which most authors had historically assumed to be a single global variable measured in terms of dimensions such as development cost, development time, reductions in scrap or rework percentages. Other memorable work, however, suggests product development performance may actually be a multidimensional construct with certain dimensions possibly at odds with one another (Driva and Pawar, 2000; Keller, 1994; Kessler, 2000). Therefore, using a global performance variable for product development can be problematic since it may hide relationships between independent variables and separate performance dimensions (Keller, 1994).

The framework emerging from the literature follows Gresov *et al.* (1989), who view performance as being composed of efficiency (the ratio of outputs obtained relative to the units of inputs or resources required to achieve those outputs), effectiveness (degree of goal

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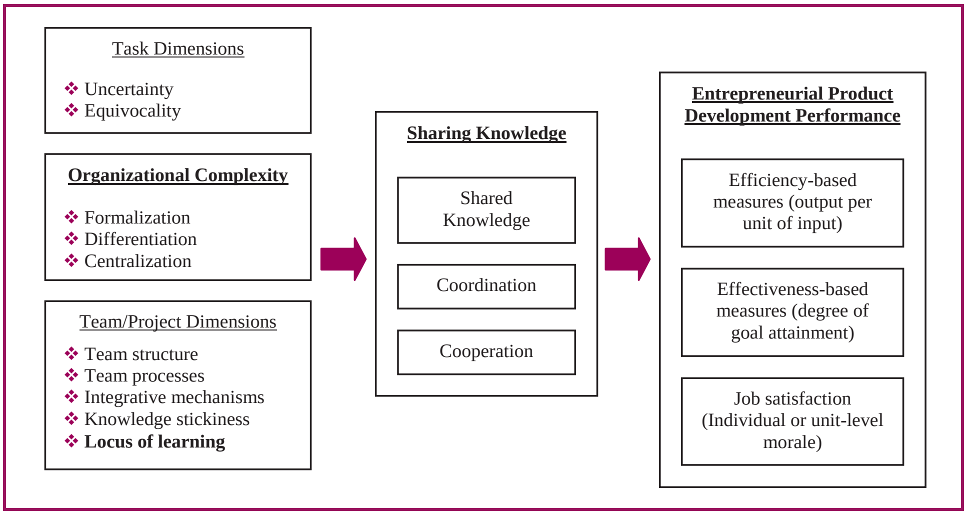
**Figure 2** Potential extensions of H&P's theoretical framework




attainment) and job satisfaction (the affective reaction or feeling by an employee). The authors consider Gresov *et al.*'s (1989) view of performance because of its socio-economic integration of economic, strategic and psychological criteria. After all, sharing knowledge is volitional, and removing affect from the mix disregards the employees who are willing to share the knowledge. Similarly, sharing knowledge is a goal-seeking behavior where the employee in an entrepreneurial firm shares knowledge towards certain organizational objectives. These dimensions account for common PDP metrics as reported by Driva and Pawar (2000) and constitute the right wing of Figure 2.

*The left wing*. The left wing of the potentially emerging framework identifies task, organizational and team factors posited to influence the creation of shared knowledge. The many integrative mechanisms identified by Galbraith (1973) include rules or programs (procedures), hierarchy, goals, slack resources, self-contained tasks, vertical information systems, and lateral relations such as liaison roles or teams. In line with the conceptual simplicity of H&P's original model, the authors visualize the variables recurring in the literature into three clusters of structural and process factors.

The first cluster captures the two task dimensions of knowledge transfer, expressed by joint research in information processing and task contingency theory highlighting the roles of uncertainty and equivocality (Sicotte and Langley, 2000; Van de Ven and Delbecq, 1974).

The second cluster follows traditional thinking in organization theory as originated by Frederick Taylor and Max Weber, and reinforced by March and Simon (1958), Cyert and March (1963), Galbraith (1973), Mintzberg (1979) and others. This organizational cluster expresses structural design complexity in terms of three dimensions: formalization, differentiation and centralization. Traditionally, formalization refers to the degree to which methods, communication modes and procedures are formally articulated. Differentiation can be either horizontal (e.g. by function) or vertical (i.e., in terms of management layers). Centralization refers to where decision-making authority is placed within the hierarchy. On the one hand, an organic design entails a less-defined or ill-defined structure that builds on informal mechanisms, sporadic growth and decentralized control; on the other hand, the traditional design is highly structured with more formal hierarchies, central rules and pre-designated governance mechanisms as common denominators. Adopting this perspective, the traditional hierarchy is seen as complex to manage and the naturalistic-organic structure as basically simpler (Burns and Stalker, 1961), even though potentially entailing sophisticated cybernetic behaviors in the sense of Ashby (1956).

It is important to note here that this study's authors acknowledge that this view's dominant position has been eroding under the dual influences of the systems approach and organic complexity theory (for which the references abound and are too numerous to cite here meaningfully). Nonetheless, it is still the one considered here for the purpose of providing a clearly contrasted research design. A primary advantage of adopting for this study the traditional if currently unpopular conception of complexity is that it provides a clear benchmark, a polar opposite of the now dominant naturalistic-organic view. Between them, these two poles allow visualizing a well-defined measurement continuum along which observed team behaviors might be clearly coded in relation to EPD.

Extending the basic H&P framework would entail adding a third cluster comprising team/project dimensions. Modern organizations generally divide knowledge work into projects, as discrete sets of tasks for teams to perform. The transfer and sharing of knowledge begins with the team. Task characteristics without reference to the cohesive unit of operation remain incomplete. By doing so, the authors attest to several authors (Brown and Eisenhardt, 1997; Susman and Dean, 1992; Susman and Ray, 1999) who take into account team structure and processes, with due regard for the requisite integrative mechanisms. Although most product development (and EPD) research assumes knowledge transfer occurs instantaneously, these transfers are often laborious, difficult and time-consuming. Following Szulanski (1996), knowledge transfer is viewed here as a process of recreating a causally ambiguous set of routines in a new setting; thus the authors foresee the eventual extension of the H&P framework to include factors affecting knowledge ‘‘stickiness’’.

Finally, this third cluster of the left wing of our framework includes the *locus* of learning, primarily referring here to the temporal and secondarily the spatial attributes of learning during product development. Since knowledge is achieved internally through experimentation, when and where these experiments take place should be important (Thomke and Reinertsen, 1998; Pisano, 1996). Experimentation can thus be classified as learning before doing (in the lab, simulation, etc.) or learning by doing (in full-scale production mode). Because of this, the authors chose to focus our data collection and analysis efforts on the effects of the temporal *locus* of learning and of organizational complexity on sharing knowledge and, hence, product development performance.

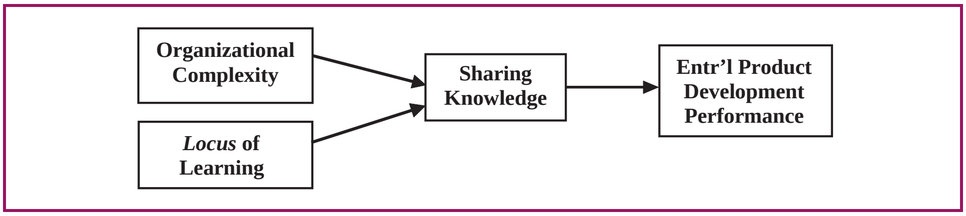
Figure 3 presents a condensed framework proposed for this specific case study, emphasizing the influence of organizational complexity as traditionally defined and that of the *locus* of learning.

## Research method

### *The four-project case study*

To investigate entrepreneurial product development and product development performance under the aegis of knowledge sharing, the authors conducted a comparative case study in a multidivisional, medium-size manufacturing firm (less than $100 million in sales) headquartered in the Midwest. The division has a separate R&D facility developing and testing new products for two recipient plants located within 60 miles of the R&D center. This case study approach follows up on earlier studies such as those of Adler and Clark (1991), Leonard-Barton (1992), von Hippel and Tyre (1995) and Hoopes and Postrel (1999).

**Figure 3** Our proposed condensed model



A unique set of historical events enabled controlling for some product and organizational factors. The two recipient facilities produced similar products and had similar histories, having been one another's main competitors in the years prior to the study. Through a series of mergers and acquisitions these two major competitors had become sister divisions within the same firm. As competitors, the plants varied in the degree of formality used in communication methods and organizational structure. These aspects were evident throughout the study. In essence, the authors were able to study two different organizations that produced fairly similar products. Table I summarizes the differences between these plants, respectively labeled ''organic'' and ''traditional''.

Four development projects were studied to explore the phenomena of knowledge sharing. The projects correspond to the cells of the 2 × 2 typology shown in Table II (projects Alpha, Beta, Gamma and Delta). Project selection was guided by criteria suggested by Kessler (2000) and conducted jointly with company executives. Projects were required to:

- have been completed within the past two years to assure currency of entrepreneurial choice, plan and action;
- contain a significant technological component as comprising the knowledge content that required sharing between technical and non-technical functions[2];
- include members spanning at least three (heterogeneous) functional areas; and
- be representative of typical projects for the entrepreneurial firm.

The projects selected were also confirmed by company executives to be approximately the same in terms of task complexity.

Alpha was a learning-before-doing project delivered to the organic recipient plant for the purpose of developing a lower-cost processing alternative to an existing bottleneck process suffering from problems of inefficiency, low capacity and poor quality. The Alpha process was akin to a continuous painting process where parts are loaded onto conveyor-propelled racks, and delivered through a series of cleaning and coating operations.

The other learning-before-doing project, Beta, was delivered to the more traditional, formalized recipient plant. Of the four projects studied, Beta and Alpha were most similar. Both were undertaken to study and improve existing problematic processes for mature product lines. Both processes involved processing part numbers in batches, but the Beta process was more of a batch process whereby assorted materials were mixed, molded, baked and formed mechanically.

**Table I** Comparison of recipient plants

| *Complexity dimension* | *Plant A (simpler organic design)* | *Plant B (traditional design)* |
|---|---|---|
| Formalization | Shopfloor processes are less formalized; greater reliance on hands-on training | Shopfloor processes are more formalized and follow a well-defined systematic procedure |
| Differentiation | Less differentiation; employees perform many types of tasks | Greater differentiation between manufacturing and engineering functions |
| Centralization | Decentralized; greater reliance on peer-to-peer communication | Centralized; greater reliance on supervisory control |

**Table II** Project classification in study and research design

| | *Organizational complexity* | |
|---|---|---|
| *Locus* of learning | Smaller and organic entities | Larger and traditional structures |
| Before-doing | I. Alpha project | II. Beta project |
| By-doing | IV. Delta project | III. Gamma project |

Moving on to the second row of Table II, the Delta project was a learning-by-doing project delivered to the same plant as Alpha. Among the four projects studied, Delta was the only one initiated for revenue generation; in this regard it differed from the initial cost reduction aim of projects Alpha, Beta and Gamma. Having already purchased new equipment, the company viewed Delta as an opportunity to develop new capabilities and market share for a segment of its business. Uncharacteristically for this firm, the Delta project and resultant product were based on a niche, high-margin strategy; not low costs relying on standardization.

Completing our $2 \times 2$ typology, the Gamma project was another learning-by-doing project delivered to the same plant as Beta. The process under development sought to provide internal capability for a metalworking operation previously outsourced to external vendors. Of all four projects, Gamma probably exhibited the least amount of risk, since the company was essentially imitating known technology currently available at its vendors. Success was mostly a matter of replicating the process capability and quality of the vendors. Operationally, Gamma was similar to Beta. Both were performed in a plant with a traditional engineering design, in which automated batch processes governed the scheduling of part numbers to minimize setup times and costs.

The firm's constraints on access prohibited a lengthy longitudinal study of active R&D projects. In lieu of this, a retrospective, *ex post* analysis strategy on recently completed projects was pursued. The study's population included those participants who had decision-making authority for the projects. All participants were involved with the project for at least three months. In total, 23 participants were interviewed.

### *Data collection*

The authors rely on a series of cases to investigate the phenomenon of knowledge sharing in EPD. The main benefit of case-study research is the rich array of dissections and detailed observations that help researchers understand complex situations. In the process, the authors surface existing assumptions and corroborate them in the light of our findings from the four cases. Such a strategy allows the comparison of existing perspectives and base conclusions in light of prior research (Yin, 1994). Figure 3 presents a condensed framework for this specific case study involving organizational complexity, the *locus* of learning, shared knowledge and product development performance.

The methods adopted for data collection followed Burns and Acar (2001), who developed a technique for extracting from subjects evidence of technical process knowledge based on Böhn's scale. Data were collected primarily through focused interviews. Focused interviews were initially developed in communications research; they are appropriate when subjects are known to have been involved in an uncontrolled but observed social situation or psychological experiment (Merton *et al.*, 1956). Owing to a request for brevity expressed by senior managers, interviews lasted about 90 minutes. Prior to the interviews, subjects were notified of the general objectives of the study and asked to review their personal files for the project. All interviews were tape-recorded with subjects' permission.

As is generally recognized (Miles and Huberman, 1994; Yin, 1994), interviews are favored over questionnaires when the researcher is interested in uncovering a diversity of relevant or unanticipated responses for exploration. The task of the interviewer is to avoid unproductive digressions by the subject while safeguarding against injecting his or her own bias. Primarily, unstructured (stimulus- and response-free) questions were used wherever possible to introduce each focal area. Semi-structured questions (where either stimulus or response is structured and the other left free) were then used for further exploration.

At the outset of our study, contextual data were obtained from the project leader for each project and displayed in a time-ordered matrix of significant events. ''Significant'' implies, at a minimum, events of knowledge acquisition (e.g. production trials, lab trials, product testing) and transfer (meetings, reports, procedures, training, problem solving sessions,

> **"While shared prior knowledge is of crucial importance to current projects, sharing resultant knowledge feeds into the organizational memory and helps modify its standard operating procedures."**

etc.). Project managers were asked to identify the ''architect'' of the process (as the scientist who designs the process is called in KM terminology)[3]. This is the person most responsible for the myriad of decisions for process steps, equipment, materials, specifications, inspection points, etc., composing the eventual process design. The process architect was assumed to be the most knowledgeable project member. For three of the four projects studied, the process architect simultaneously served as project manager.

Once identified, the process architect was queried for output variables associated with the project considered critical for product quality. This step was aided by analysis of blueprints, customer specifications and process routings in production. On the surface the list appeared rather lengthy, but when probed the architect was usually able to narrow down the list of critical output variables to less than a dozen, along with corresponding measuring methods, units of measure and effective control limits. Project files were reviewed for contextual materials such as progress reports, timelines, minutes of meetings and any other forms of communication pertaining to coordination or the creation of shared knowledge. Finally, project managers were interviewed for approximately 90 minutes and asked general questions about the events of the project, searching for instances of problems encountered during the project.

Three forms of documentation served as interview guides. The first guide was a time-ordered matrix of events for each project, extracted by project files and a series of open-ended interviews with project managers. The second interview guide, a knowledge tree diagram, was more complicated to create but was instrumental in extracting evidence of knowledge depth held by subjects. The tree diagram was developed through interviews with the ''architect'' of each process. An example of such a knowledge tree is shown in the Appendix, Figure A1.

The final interview guide was a list of open-ended questions constructed and refined based on guidelines set forth by several authors (Glesne and Peshkin, 1992; Kvale, 1996; Merton *et al.*, 1956). The list of areas of interest for this study was rather large, including elements of the subject's background aiding or hindering knowledge transfer, effectiveness of various communication modes deployed for the transfers, evidence of subject's resultant knowledge (based on the knowledge tree of the process), influence of knowledge on performance measures, and underlying causes of problems encountered during the process. The detailed interview data took several weeks to gather and record on tape, and several months to analyze and code.

When probing for knowledge depth held by the subject, the knowledge tree diagram and interview questions were used as a guide. Whenever possible, a cued transition was made based on the subject's mention of quality or some other technical aspect of the project. (You mentioned quality. How do you measure quality? How do you know when the product is ''high quality''?). From here, the pattern of questions usually followed Böhn's (1994) classification of knowledge levels (How is ''*y*'' measured? Which input variables *x* do you think influences y the most? Why does *x* influence *y*? What, besides *y*, does *x* influence?). Several variables and relationships were explored with each subject. Probing questions were asked until either a ''did not know/do not recall'' response or evidence of a lengthy explanation had been collected.

### *Data analysis*

The greatest challenge of this study was to develop a way to capture the knowledge held by its participants. Böhn's (1994) scale is useful as it measures technical knowledge about one variable, but is not applicable for quantifying knowledge for all the process variables held by individuals. Moving toward individual knowledge quantification, the authors conducted an initial analysis of all interview transcript data, which revealed three pertinent, discernible knowledge dimensions: depth, scope, and action. Space limitations here prevent us from elaborating all designs and tactics the authors pursued. It is felt that the reader can inductively gather an understanding of the issues involved as he or she reads the following description of the coding procedure devised for use on interview transcripts.

Each interview transcript was segmented into passages, typically around 100 words in length. Passages containing potential evidence of process knowledge were selected (usually identified by mention of some process variable). To avoid over-filtering, those passages were then analysed for content and classified as: casual observations or in-depth discussions. *Casual observations* occasionally contained evidence of process knowledge and were simply coded as: (1a) useful, or (1b) not useful.

Useful information was mostly gleaned from in-depth discussions rather than the casual observations made by the participants. In-depth discussions were classified as: (2a) single- or (2b) multi-problem based on the number of problems mentioned by the subject. At times, subjects would mention a single problem that did not warrant extensive explanation (akin to simple cause-effect). At other times, the subject would describe a more sophisticated multi-faceted problem requiring more extensive explanation. If one were to only consider the number of in-depth discussions articulated per subject, viewing single problems in the same light as multifaceted problems would be misleading. Multi-faceted problems required far greater understanding on the part of the participants to articulate.

Passages were analyzed along three dimensions: depth, scope and action/response. Depth of knowledge demonstrated by the subject was coded as script, analogy or science. ''Scripted'' responses represented the lowest amount of evidence of knowledge and usually consisted only of a recitation of the relevant standard operating procedure (SOP); probing in this case led to the respondent claiming that he or she did not know or no longer recalled. The ''Science'' responses were those most complete and based on logical or scientific principles. In-between those polar ends, ''Analogy'' responses described the phenomenon in terms of an analogy in lieu of scientific principles.

Scope reflects the scope of effects of process changes mentioned for one variable on other output variables (a requisite feature when trying to capture multifaceted problems), and was coded as direct, partially systemic or fully systemic. Passages were coded as ''Direct'' when, upon mentioning a change in an input variable, respondents could only indicate the effect of the change in one output variable, even after probing. ''Partially systemic'' responses included a description of the change on two output variables. ''Fully systemic'' responses included the effects on three or more variables.

While scope refers to changes across branches of the knowledge tree, the Action dimension characterizes the course of action proposed by the subject. Its coding categories consisted of direct, upstream and systemic. They essentially represented action guided by the current branch of the knowledge tree. ''Direct'' responses included only one possible action taken even after probing, namely a simple cause-effect description. ''Upstream'' responses showed knowledge of either feedforward or feedback control, where more than one action was cited. ''Systemic'' responses included at least three possible actions that could be taken and reflected a greater understanding of the whole process.

### *Tabulation of results*

The results of this coding scheme are presented in Tables III and IV. Table III's columns list the subjects for the Alpha and Beta projects[4]. Its first row indicates the types of passages coded; its other three rows give the breakdown by depth, scope and action. During the development of the knowledge tree diagrams, interviewing the process architects yielded

**Table III** Knowledge coding results (number of passages in interview text)

| | | *Alpha* | | | | *Beta* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Subject ID* → | | *A1* | *A2* | *A3* | *A4* | *B1* | *B2* | *B3* | *B4* | *B5* |
| Passages | Casual observations | > 20 | 5 | 14 | 4 | > 20 | 4 | 7 | 6 | 7 |
| | Single problem | 10 | 7 | 5 | 9 | 10 | 4 | 4 | 6 | 6 |
| | Many problems | 10 | | 1 | | 10 | 4 | 1 | | |
| | Total passages | 20 | 7 | 6 | 9 | 20 | 8 | 5 | 6 | 6 |
| Depth | Script | | | | 8 | | 1 | 2 | 5 | 4 |
| | Analogy | | | | | | | 1 | | |
| | Science | 20 | 7 | 6 | 1 | 20 | 7 | 2 | 1 | 2 |
| Scope | Direct | | | 2 | 6 | | 1 | 5 | 5 | 2 |
| | Partial systemic | | 3 | 1 | 3 | | 4 | | 1 | 4 |
| | Full systemic | 20 | 4 | 3 | | 20 | 3 | | | |
| Action | Direct | | 1 | | 7 | | 1 | 3 | 4 | 5 |
| | Upstream | | 4 | 1 | 2 | | 2 | 2 | 2 | 1 |
| | Systemic | 20 | 2 | 5 | | 20 | 5 | | | |

(*Project* spans the Alpha and Beta column groups.)

**Table IV** Knowledge coding results (% responses of text passages in each category)

| | *Total passages* | *Low* | *Medium* | *High* |
|---|---|---|---|---|
| *Alpha subject ID* | | | | |
| A1 | < 20 | | | |
| A1 depth | | 0 | 0 | 100 |
| A1 scope | | 0 | 0 | 100 |
| A1 action | | 0 | 0 | 100 |
| A2 | 7 | | | |
| A2 depth | | 0 | 0 | 100 |
| A2 scope | | 0 | 43 | 57 |
| A2 action | | 14 | 57 | 29 |
| A3 | 6 | | | |
| A3 depth | | 0 | 0 | 100 |
| A3 scope | | 33 | 17 | 50 |
| A3 action | | 0 | 17 | 83 |
| A4 | 9 | | | |
| A4 depth | | 89 | 0 | 11 |
| A4 scope | | 67 | 33 | 0 |
| A4 action | | 78 | 22 | 0 |
| *Gamma subject ID* | | | | |
| G1 | < 20 | | | |
| G1 depth | | 0 | 0 | 100 |
| G1 scope | | 0 | 0 | 100 |
| G1 action | | 0 | 0 | 100 |
| G2 | 8 | | | |
| G2 depth | | 38 | 0 | 63 |
| G2 scope | | 38 | 50 | 13 |
| G2 action | | 75 | 0 | 25 |
| G3 | 6 | | | |
| G3 depth | | 100 | 0 | 0 |
| G3 scope | | 83 | 17 | 0 |
| G3 action | | 83 | 17 | 0 |
| G4 | 5 | | | |
| G4 depth | | 80 | 20 | 0 |
| G4 scope | | 80 | 20 | 0 |
| G4 action | | 80 | 20 | 0 |

Notes: Depth: 1 = Script, 2 = Analogy, 3 = Science; Scope: 1 = Direct, 2 = Partially systemic, 3 = Fully systemic; Action: 1 = Direct, 2 = Upstream, 3 = Systemic more than 20 passages entailing the highest form of knowledge (Depth = science-level, Scope = fully systemic, Action = systemic).

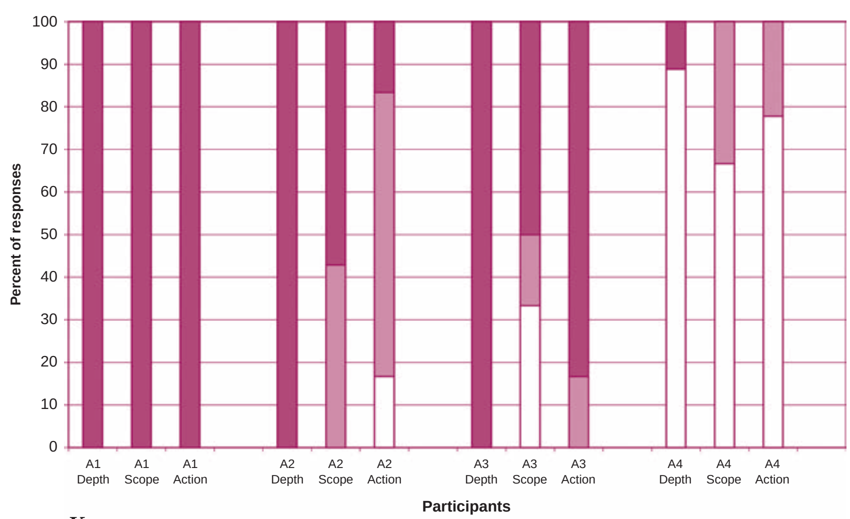
Since interviews varied in length and some transcripts generated more useful passages than other, the numbers have been normalized for total number of passages. Table IV shows, for projects Alpha and Gamma, the breakdown of depth, scope and action as percentages to overcome the bias of interview length due to the number of useful passages in the records of the interviews.

Access and resource constraints imposed by the firm prevented a longitudinal study of all projects. The case study was of sufficient size to produce large volumes of documents and interview transcripts from which partial conclusions could be drawn. Case write-ups were written for each project to support cross-case analyses based on the timeline of events generated by interviews. Space limitations here prevent extensive within-case analysis. Additionally, such analysis would be inappropriate given the firm's constraints on our data collection efforts.

Although data saturation was not reached, sufficient data were obtained consistently for each project to substantiate the analysis. Several methodological authors guided our qualitative analyses, including Miles and Huberman (1994), Yin (1994) and Eisenhardt (1989). Internal validity was sought by triangulating multiple sources of evidence, including contextual information, interview transcripts and a questionnaire administered to participants (Yin, 1994). When appropriate, conflicting evidence was resolved by a follow-up interview with the project manager.

Knowledge-coding graphs were created to visually depict the data from Tables III and IV for all projects (Figures 4 and 5 illustrate the approach on two of the projects). Each graph showed the coding results of one project. Within each graph, three columns were drawn for each project member. From left to right, process architects are shown first, followed by other members shown in approximate decreasing order of knowledge depth. The vertical axis represents frequency of responses in each knowledge dimension of depth, scope and action. As mentioned earlier, depth is coded as ''script'' (low), ''analogy'' (medium) and ''science'' (high). Scope is similarly ordered into three levels labeled ''direct'', ''partially

**Figure 4** Knowledge coding results by participant: Alpha project (learning before doing, organic plant)

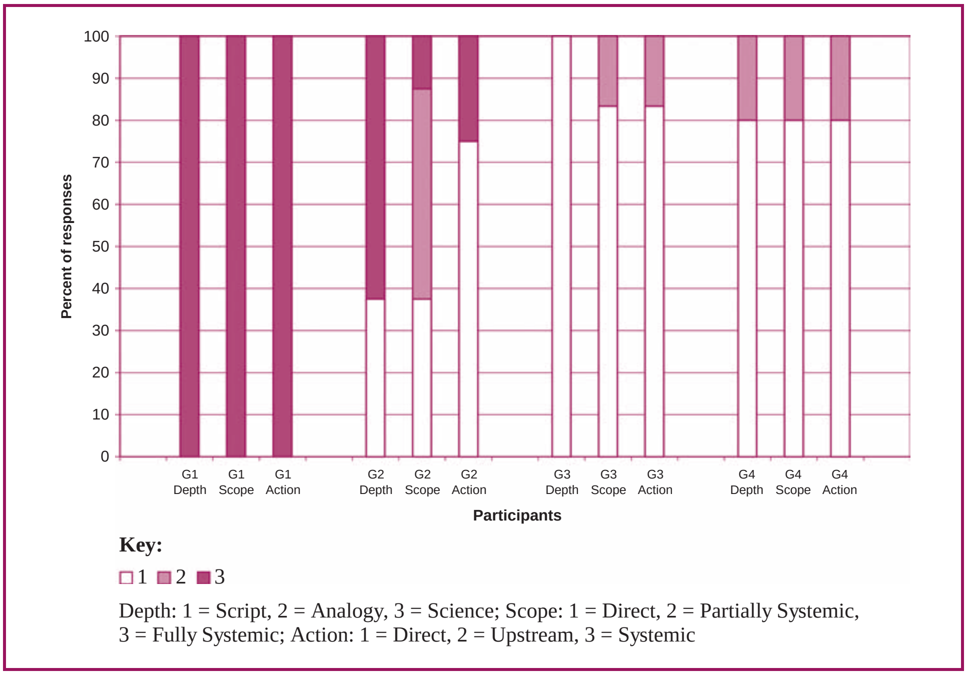



**Key:**

1 2 3

Depth: 1 = Script, 2 = Analogy, 3 = Science; Scope: 1 = Direct, 2 = Partially Systemic, 3 = Fully Systemic; Action: 1 = Direct, 2 = Upstream, 3 = Systemic

**Figure 5** Knowledge coding results by participant: Gamma project (learning by doing, traditional plant)




systemic'' and ''fully systemic''; and action as ''direct'' (low), ''upstream'' (medium) and ''systemic'' (high).

Analysis was initiated by visual comparison of the knowledge coding graphs for projects in the recipient plants. Darker shades suggest more frequent evidence of knowledge sharing at deeper levels. Visual observation suggested both projects received by the organic plant had more areas of darker shades, leading to the conclusion that the organic plant design exhibited greater knowledge sharing at deeper levels for both projects.

To test this visual observation, average responses were calculated at the high, medium and low levels (the black, gray and white shades of the columns) for each project. Knowledge architects' percentages were ignored since they were the primary source and not a recipient of knowledge, but their inclusion would not have materially affected the results. These are summarized in Table V.

## Surfacing themes of knowledge sharing

### *Organizational complexity and shared knowledge*

Following traditional authors such as March and Simon (1958), Cyert and March (1963) and Galbraith (1973), the authors conceptualize organizational complexity as comprising

**Table V** Average knowledge-level responses for traditional and organic plants

| *Knowledge level (Depth, scope, action)* | *Locus* of learning | *Traditional (%)* | *Organic (%)* | *Difference (Traditional-Organic)* |
|---|---|---|---|---|
| High (science, fully systemic, systemic) | Before doing | 23 | *86* | −25 |
| | By doing | 11 | *43* | −32 |
| Medium (analogy, partially systemic, upstream) | Before doing | 22 | 21 | +1 |
| | By doing | 16 | 30 | −14 |
| Low (script, direct, direct) | Before doing | *55* | 31 | +24 |
| | By doing | *73* | 27 | +46 |

formalization, differentiation and centralization. In traditional thinking, one would expect the more complex organizations to be more bureaucratic, with greater differentiation, more formalized methods and more centralized decision making. What is the interplay of structural complexity and knowledge sharing? Traditionally, two plausible arguments have been advanced. Information processing theory suggests a positive relationship between organizational complexity and the sharing of knowledge. Assuming that sufficient level of integration across functions is maintained, more complex entrepreneurial organizations (in the sense of more pronounced hierarchy, greater job specialization, more formal communication methods) should promote greater transfer and sharing of knowledge because the division of labor into narrow specialties creates the need for cross-pollination.

Alternatively, task contingency theory and its contemporary offshoots suggest that a discretionary, rather than traditional, design mode should improve performance for non-routine tasks (Van de Ven and Delbecq, 1974). Since the EPD environment is high in complexity, uncertainty and interdependence, the features of an organic structure suggest that lower bureaucratic complexity (in the sense of low standardization, discretion at the hands of employees, substantial informal communication) may be conducive to knowledge sharing. Thus the past few decades have promoted the organic structure as a paradigm for organizational knowledge sharing because the organic structure aims at increasing communication across traditional functional silos (Burns and Stalker, 1961).

Yet, for traditional authors, knowledge sharing is more than creating a communication network; it requires instituting and establishing formal rules, policies and governance structures that can promote knowledge sharing and deter knowledge hoarding. In the absence of formalized structure and standardized routines, the free-flowing discretionary structure may constrain knowledge sharing and cross-pollination. As noted earlier, this is no longer the dominant view, and contradicting studies have been published for a number of decades. Still, for firms lacking considerable resource slack (Cyert and March, 1963), wouldn't a formalized structure be more appropriate and conducive to knowledge sharing? The position taken in this study is one of healthy skepticism a sort of *tabula rasa* that would allow the field of EPD to start afresh. Whether and how knowledge sharing actually happens in EPD is an empirical proposition that contemporary research should explore from a novel, contingency-based angle.

A view held by many organization theorists is that learning may be dictated by an entrepreneurial organization's ''absorptive capacity''; that is, its ability to process external information (Cohen and Levinthal, 1990). According to Leavy (1996), entrepreneurial firms face two structural challenges: one is to share and integrate knowledge for innovation and EPD; the second is to restructure the firm from a free-flowing entity to a formal, complex structure built on resource and communication layers. Several authors have found absorptive capacity to be developed cumulatively over time, be path-dependent and built upon prior investments in its members' individual absorptive capacities (Lane and Lubatkin, 1998). Therefore, a complex traditionally structured entrepreneurial organization with higher degrees of formalization of roles, differentiation of functions and centralization of control, would increase its absorptive capacity to share entrepreneurial knowledge internally. Lacking a preset structure, a simpler entrepreneurial organization may create knowledge but fail to absorb and assimilate it in the absence of formal policies and procedures. This line of reasoning implies that a more complex entrepreneurial organization has greater absorptive capacity: in the presence of appropriate knowledge integration mechanisms, one should find more traditionally structured entrepreneurial organizations to be associated with higher levels of shared knowledge across project participants than more organically streamlined entities.

From this perspective, the present findings first appear puzzling. Table V clearly shows that participants in the organic plant projects had more frequent responses in the high and medium categories compared to traditionally structured plant participants, whose knowledge responses more frequently classified as low knowledge. These results appear to contradict the authors' expectations. Taking the results at face value, one might conclude they were due to the smaller organic plant's use of more effective mechanisms for knowledge sharing. That is, the organic plant design encouraged greater face-to-face interaction, which in turn created a superior level of deep knowledge sharing than the SOPs used by the traditional, less organic plant. This interpretation would be congruent with Burns and Stalker's (1961) view of the organic organization; however, it is at odds with data obtained by transcripts and other qualitative information gathered by the interviewer. To interpret the present results correctly as providing insights toward an emerging theory of entrepreneurial product development, the authors need an explanation more in line with what emerged from the interviews.

One plausible explanation would be that individual and project attributes influence knowledge sharing more substantially than organizational design factors. In this study, individual- and project-level factors did appear to influence knowledge sharing to a greater extent than organization design. Table VI shows the percentage of high knowledge responses in decreasing order against the subjects' technical level of education and work experience. Not surprisingly, these data suggest in-depth education to be a significant and necessary condition for acquiring deep enough knowledge to produce scientific, systemic responses (Churchman, 1968; Nass, 1994). Substantial work experience served as a proxy to technical education in a few cases, because those participants did receive advanced training and education in technical seminars. This finding concurs with the notion of absorptive capacity both at the individual (Cohen and Levinthal, 1990) and group levels (Szulanski, 1996, 2000).

On the basis of our results, it would be tempting to conclude that organic organizations could be generating greater levels of shared knowledge mostly as a direct consequence of their hiring practices. But team-based organizations are frequently prescribed by management consultants as a universal solution to organizational problems since the team structure overcomes dysfunctionalities associated with functional differentiation. Management consultants operate using a holonic architecture (Koestler, 1967) – a stable team organization combining autonomy and cooperation across superordinate and subordinate hierarchies (Simon, 1991). The assumption is that a prescribed knowledge interchange format will automatically create a shared, and perfectly understandable, knowledge ontology in a holonic architecture. If one were to regard the wider scope of product development activities as including conceptualization or innovation, then a primary goal would be to improve communication and knowledge sharing. Hence, cross-functional teams, as holons, would be the logical organizational form. Yet, research pays little notice to a reality that sometimes fails to agree on a knowledge interchange format or shared ontology

**Table VI** Participants' level of education and work experience

| *Participant* | *Knowledge level* *Low (%)* | *Medium (%)* | *High (%)* | *Technical degrees obtained* | *Work experience (Years)* |
|---|---|---|---|---|---|
| A1 | 0 | 0 | 100 | Bachelor's degree in chemistry | 15 |
| B1 | 0 | 0 | 100 | Bachelor's degree in engineering | 25 |
| D1 | 0 | 0 | 100 | Associate degree in material science | 30 |
| G1 | 0 | 0 | 100 | Bachelor's degree in engineering | 4 |
| A3 | 11 | 11 | 78 | Bachelor's degree in chemistry, engineering | 3 |
| D2 | 17 | 17 | 67 | Bachelor's degree in engineering | 9 |
| B2 | 13 | 25 | 63 | Bachelor's degree in engineering | 8 |
| D5 | 50 | 42 | 58 | None | 22 |
| D3 | 17 | 25 | 58 | Bachelor's degree in engineering | 12 |
| A2 | 5 | 33 | 57 | Bachelor's degree in chemistry | 4 |
| G2 | 50 | 17 | 34 | Bachelor's degree in engineering | 4 |
| B3 | 67 | 20 | 13 | Associate degree in material science | 4 |
| B5 | 61 | 28 | 11 | Bachelor's degree in engineering | 9 |
| D4 | 42 | 50 | 8 | Associate degree in material science | 11 |
| B4 | 78 | 17 | 6 | None | 7 |
| A4 | 78 | 18 | 4 | None | 10 |
| G4 | 80 | 20 | 0 | None | 11 |
| G3 | 89 | 11 | 0 | None | 4 |

– leading to persistent knowledge sharing and transfer problems. Even if there is a collective or shared intelligence from a holonic architecture, it may be remiss to assume that a team structure would be a sufficient condition.

This is where the case-study method for exploring the possibility of new grounded theory (Glaser and Strauss, 1967) truly pays off: the interview data studied here reveal a phenomenon in line with traditional organization theory occurring within the traditional plant, but that ran counter to views expressed in the popular management press and that the authors initially missed. In the latter stages of design and implementation the authors studied, sharing more knowledge was not *per se* the primary objective. For the organic plant lacking SOPs for operators to follow, knowledge sharing was a necessity for effective operation. But having SOP resources on which to rely, the more traditional plant simply focused its efforts on streamlining its processes. Success in that predictable environment was not predicated on increasing knowledge sharing for better operation, but reducing it in search of the larger goal of reducing costs for direct labor and quality (e.g., rework and scrap costs). Therefore, the traditional organizational design can add value when SOPs are established and the focus is on routinization rather than the creation of shared knowledge. This is important for successful entrepreneurs who, having reached the take-off phase, have to wrestle with structuring their projects and assign appropriate participants to reap the best yield from their knowledge workers.

Based on this observation, the nature of shared knowledge can be clarified. The authors propose that shared knowledge is made up of two parts. In entrepreneurial product development, shared knowledge prior to the start of process design is highly beneficial to the joint problem-solving design stage, since it enables decision makers to be cognizant of design constraints outside their expertise. On the other hand, shared knowledge resulting from the subsequent implementation phase is primarily associated with maintaining production quality over the long term[5].

While shared prior knowledge is of crucial importance to current projects, sharing resultant knowledge feeds into the organizational memory and helps modify its SOPs. Project-oriented organizations may pursue a short-term profitability strategy that could curtail the sharing of resultant knowledge, at least temporarily. Whether or not this approach is sustainable depends on several factors such as the life-cycle of the product, the process monitoring ability in the plant, the availability of skilled labor, and so on. Of primary importance in practice is whether the development of prior shared knowledge by the process architect, and some prior updating of the SOPs as part of process design, effectively preempts the need for subsequent knowledge sharing.

Thus this study's approach's direct focus on the nature and depth of knowledge, complementary to Hoopes and Postrel's (1999) focus on knowledge-transfer glitches, yields useful insights. Although in line with traditional mainstream theory, the insights provided by the study are useful in that they appear contrarian to much of the current consulting and popular press literature preoccupied mostly with the organic organization.

### Locus *of learning and shared knowledge*

As used in this study, *locus* of learning, referred to temporal and spatial attributes of learning during product development and was categorized as either: experimentation before-doing (mostly in a lab setting) or learning-by-doing (pseudo-experimentation in the production environment). Assuming ''more is better'' with respect to learning by experimentation, the learning-before-doing strategy was thought to produce higher levels of shared knowledge in terms of Böhn's hierarchy. Yet Pisano (1996) found that learning by doing is the preferred strategy when there is a lack of theoretical and practical knowledge about production modalities. In such cases the manufacturing plant is as much a place of learning as the R&D laboratory. In support, Gupta and Wilemon (1999) found managers perceived early involvement of different functional groups as an important factor of product development success. The implication is that early involvement may improve entrepreneurial performance since it increases the opportunity for members to share their knowledge about a process. Similarly, software entrepreneurs often use joint application development (JAD) whereby the firm initiates knowledge sharing by bringing together diverse participants such as existing and potential users, graphics, designers, software engineers, quality control, cost accountants and executives to the same table prior to software release (production).

On the other hand, Pisano (1996) also found that learning before doing is the preferred strategy when sufficient theoretical and practical knowledge about production behavior exists, and Szulanski (1996) found that the credibility of the source of knowledge during transfer (in this case, R&D) influences the degree of transfer. Early experimentation should also lead to increased credibility on the part of R&D when transferring knowledge to production. Learning-before-doing may well prove superior because it emphasizes controlled experimentation to identify input-output variables and their relationships (Böhn, 1994). Because of the potential for missed opportunities, learning by doing may turn out into a costly proposition for the entrepreneur as it creates intra-functional, rather than cross-functional, knowledge sharing – building stock without flow.

Guided by previous research the authors expected that, in otherwise comparable EPD projects, a learning-before-doing strategy will be associated with higher levels of shared knowledge in entrepreneurial firms than a learning-by-doing strategy, assuming knowledge is successfully conveyed to other functional areas. To evaluate this view, a visual comparison can be made of the knowledge sharing graphs (e.g. Figures 4 and 5) for the before-doing and by-doing projects. The pertinent average knowledge levels are shown in Table VII. Results attest to the fact and suggest the before-doing mode produces a higher frequency of responses in the high knowledge category. The findings from our cases thus confirm Pisano's (1996) view that the timing of technology transfer to production is important to knowledge sharing.

Clearly, the degree of absorptive capacity comes into play here as well. Sorting Table VI data by project (not shown) tends to support this view. In EPD projects, a higher absorptive capacity among functional members allows a more seamless sharing of knowledge. The level of knowledge of members creates the necessary prelude to knowledge sharing. Higher absorptive capacity allows members to easily understand and integrate various sources of knowledge, thus making knowledge sharing easier (Lichtenthaler and Lichtenthaler, 2009). The initial argument, namely that lab experimentation permits more extensive exploration of the design solution space, appears to be the main underlying cause of these results. The interview transcript data also suggest that learning before doing increases source credibility; this, in turn, reduces knowledge stickiness, as also found by Szulanski (1996). When engineers and process architects convey knowledge that is more complete and repeatable, recipients perceive them as credible.

The interviews with the project participants enabled detection of discernible levels of knowledge within subjects. As mentioned previously, the architect was the most knowledgeable person for a process effectively creating the knowledge ''tree'' for the process. Architects could describe each ''branch'', where the root of the branch represented an output variable. They could articulate the direct influence of input variables on output variables; and also predict the influence of input variable changes on other output variables. The challenge of the architect is to replicate the knowledge ''core'' as described by Szulanski (2000), i.e. the laboratory process in the production environment.

**Table VII** Average knowledge-level responses, learning before- and by-doing projects

| *Knowledge level (Depth, scope, action)* | *Plant* | *Before doing (%)* | *By doing (%)* | *Difference (Before-By doing* |
|---|---|---|---|---|
| High (science, fully systemic, systemic) | Traditional | 23 | 11 | +12 |
| | Organic | 48 | 43 | +5 |
| Medium (analogy, partially systemic, upstream) | Traditional | 22 | 16 | +6 |
| | Organic | 21 | 30 | −9 |
| Low (script, direct, direct) | Traditional | 55 | 73 | −18 |

Given the constraints in the production environment, this is a difficult task, as evidence by this passage from one process architect:

> *Interviewer*: If you had to do about training a new engineer for this process, how would you go about doing it?
>
> *Subject*: Whew. I don't know. It's too overwhelming to give them a book to read, there are so many interactions. They usually fall into the trap where they get away with something once, they think they can do it all the time. When other factors aren't lined up perfectly as in the first time, they run into problems. They say to me, ''Well, we were able to do this the last time.'' They don't understand there are so many combinations of (array of input variables) that you're processing, the incoming materials, there's all these things coming together [. . .] You gotta get the right combination of all of those (parameters). It's a difficult concept to grasp for a lot of people. You try to set up the process to tell them what they must do, knowing that they don't have to hold all these conditions, but you want them to at least try.

Replication of the knowledge ''core'' is made possible with help of the process engineer residing at the plant who typically had knowledge of production equipment and labor capabilities. Typically process engineers understood many ''branches'' of the tree (input variables influencing one output variables), although they did not necessarily understand all underlying phenomena completely. Technicians, on the other hand, did not usually have significant involvement in the actual process design; rather, their role constituted maintenance activities such as scheduling workflow, ordering materials, minor troubleshooting and assistance with machine setup for new products. The data suggests technicians' process knowledge to be lower than engineers with a focused knowledge of critical output variables related to their position.

This latter finding provides a caveat to viewing the entrepreneur as an impulsive visionary. Learning-by-doing often creates serendipitous knowledge as a by-product of production (Young, 1993). Such knowledge is a random and unsystematic acquisition. For entrepreneurial firms, resource scarcity often requires them to learn ''on the fly''. Unfortunately, learning-by-doing is often bounded (Young, 1993) and may increase knowledge hoarding from random knowledge acquisitions rather than patterned knowledge sharing. In light of the in-depth interviews, the present authors do not contest the importance of knowledge from learning by doing; rather, they emphasize the need for experimentation in entrepreneurial firms to mindfully sift useful knowledge discoveries from spurious ones, thus consciously systematizing a culture of knowledge sharing due to learning before doing. Consider the following interview excerpts that differentiate the engineer/process architect's knowledge from learning before doing versus the technician/operator's knowledge from learning by doing. In this first excerpt below, the subject is the engineer/process architect:

> *Int.*: Let's say you cut a part and get a burr (a kind of quality defect). What are some other things that you can change to eliminate it?
>
> *Subject*: You could slow the feed rate down, you can add air pressure so it would blow the material out of the way, or give it more power. Mostly slowing it down. More power probably won't affect it [. . .]
>
> *Int.*: How do you change power?
>
> *Subject*: There is a maximum value, then there's the duty cycle where, it's not a continuous beam, it's a pulse. The duty cycle controls how much you're on, maybe 90 percent on 10 percent off, it's going so fast it looks like a continuous beam, but it's not. Then there's also a setting called dynamic power setting. The faster it goes, the closer to the maximum power setting it will be. If the head is going slower, the power reduces, maybe if you have a sharp corner... So the dynamic power setting controls whether or not you're getting a good cut.
>
> *Int.*: So when you get this burr, what would be the first thing you would change?
>
> *Subject*: The feed rate. Then the gas pressure.
>
> *Int.*: I've heard of something called ''J-ing'' (another type of defect)?
>
> *Subject*: Yes.
>
> *Int.*: That is on the side of the part, yes? What causes that?
>
> *Subject*: That's when you try to cut the part too fast.

*Int.*: How do you fix that?

*Subject*: You either slow it down, or add more power. What's happening is, the laser beam is not all the way through the material. And then you're moving along trying to cut. So at the bottom of the parts, you'll see the marks from the beam trailing off. That means you're cutting too fast. So you either have to slow it down, which would let the beam go through the part, or you have to increase the power to get the beam through the part. That usually fixes it. One of the operators says ''slower is always better''.

*Int.*: Is slower always better?

*Subject*: No. Sometimes you can go faster, you just give it more power. Why cut at 10 inches per minute with 50 watts, when you can cut at 20 inches per minute with 100 watts? You would get a lot more production if you cut at 20 inches per minute.

The next excerpt, a description of essentially the same process phenomena, comes from an interview with a technician who operates the machine – and thus expresses the knowledge transferred to him:

*Int.*: Let's say you get a burr. What are some of the things you can do to correct it?

*Subject*: It would probably be easier to show you my ''cheat sheet'' that I made. I made notes for all these things. (Referring to notes from his book) Usually for the burr, I would probably add more oxygen or maybe speed the machine up.

*Int.*: What does increasing the oxygen do?

*Subject*: I really don't know exactly. In my mind, it's just like putting more pressure to it. It may be more pressure has a cooling effect. I don't know really know.

*Int.*: You have a lot of information in this book.

*Subject*: Yeah. Some of these things I made up myself and I just leave stored on the computer. We have all the specs (parameters) for every part we've cut back there [. . .]

*Int.*: What is ''J-ing''?

*Subject*: That's when you don't have a straight line on the cut.

*Int.*: What do you do to correct that?

*Subject*: I would adjust the feed rate, lower it. Most of this I learned from trial and error. The only thing I know about the feed rate is if it spending too much time in one spot, it's going to burn. If it's going to fast, it's not going to cut the part right [. . .]

*Int.*: (Reviewing *Subject*'s notes) For dross (another quality defect), what would you change first?

*Subject*: I see here it says alter the cutting pressure. I'm not totally certain why that is. All I know is, increasing cutting pressure usually makes it go way.

The excerpts provide a snapshot that supports the creation of an EPD culture of learning before doing as a mechanism to ensure consistency and emphasizes *a priori* planning, since learning before doing requires *ex ante* planning. Facing resource constraints, EPD require some form of routinized structure of knowledge transfers as a way to reduce variance in SOPs. A planned routinization (and thereafter institutionalization) of knowledge transfers from learning before doing establishes a normative or systematic, rather than a formative or more organic view, of learning in EPD. While this view limits organic evolution of knowledge transfers and learning for product development, systematic planning and routinization often aids EPD operations by removing the evanescence of adaptive, unstructured, organic approaches which may be more apt for larger firms with greater resource slack.

In an age where resource constraints loom large in the face of shifting measures of knowledge transfers, this research reconstitutes our understanding of knowledge transfers by scrutinizing a popular knowledge integration framework in light of practice – a step forward in ensuring EPD direction and purpose. Therefore, relying on popular, prescriptive frameworks (such as H&P's) as best industry practices often provides a decisional respite from uncertainty.

### *Limitations*

A study is scoped by its theoretical premise. As such, H&P's framework of knowledge and learning underpinning our inquiry limits conclusions and observations based on it. While the H&P framework remains one of the more popular frameworks for investigating knowledge integration mechanisms, inherent limitations of the framework remain. Primarily, knowledge integration mechanisms convey the formal processes and structures for the capture, analysis, interpretation and integration of market and cross-functional knowledge (Zahra *et al.*, 2000). As a result, this research is limitedly scoped by knowledge integration mechanisms as the basis of knowledge transfers. Yet EPD, as an extension of the product innovation literature, also looks at two other complementing facets:

1. market knowledge that highlights the firm's knowledge about its customers and competitors (Kohli and Jaworski, 1990); and
2. cross-functional collaboration that highlights the degree of cooperation and the extent of cross-functional representation (e.g. finance, marketing, R&D) in the product innovation process (Li and Calantone, 1998; Pitt and MacVaugh, 2008).

Future research on knowledge management may add useful insights by tying together these knowledge complementarities to alleviate concerns of theoretical limitations of this study.

Empirically, the research findings provide grounds for a return to the traditional concepts of organizational structuring (e.g., March and Simon, 1958; Galbraith, 1973), but the fact that they are grounded in an empirical case-study of a single manufacturing firm limits their generalizability. The choice of four separate projects studied in two facilities mitigates this limitation but does not negate it. In addition, the present results pertain mostly to latter stages of design and implementation; researchers should be cautioned about generalizing the findings presented here to the conceptualization or innovation stages of product development.

The difference between EPD and product development in large organizations may not have been fully captured in this study based on a medium-size firm. Large organizations have greater resource slack and have more intensive mechanisms for human capital selection, recruitment and management. Because small entrepreneurial firms are more exposed to market and operational shifts, coordination and integration of knowledge for product development are imperatives. Moreover, entrepreneurial firms have a smaller product pipeline than larger organizations, necessitating better and often bootstrapped knowledge management practices.

The method used here did not attempt to challenge the knowledge held by process architects. As part of the method, theses architects helped produce a knowledge representation scheme that was presumed to be complete. There may have been cases where the architect did not represent the knowledge completely (although the authors encountered no evidence of this). The authors were aided by the mostly unidirectional flow of knowledge in our projects between one source and several recipients. It would be difficult to faithfully replicate the method of this study in situations with multiple sources and fewer recipients, especially when consensus about the underlying knowledge is difficult to achieve. As such, the interview method would benefit from a more rigorous administration.

Task contingency theory suggests optimal organization design depends on task complexity. Since the authors held task complexity fairly constant across projects, the conclusions drawn here are not generalizable to all types of tasks. Researchers should bear this in mind when adapting either methods or findings from this study to activities beyond technology transfer, and might want to take into account in their planning the difficulties specific to interview-based investigations.

Further, the nature of a retrospective study introduces a form of selection bias since it addresses successful products, which have made it to the market; yet even during development and ramp-up, there are occasions when projects might be abandoned. It may be that knowledge sharing facilitates prudent decision making such that the chance and degree of success in the marketplace are increased. Future comparative studies of both successful and unsuccessful projects would be more revealing, since they could effectively elaborate cause-effect relationships between knowledge and performance. In

> **"In an entrepreneurial arena facing increasing resource constraints, knowledge workers must not only be cognizant of their specific expertise, but also be able to synthesize and transfer their knowledge to other groups."**

our case, time constraints imposed by the subject firm precluded a drawn-out study of this type.

Among the core findings of this paper, one is how traditional organizational designs add value ''when SOPs are established and the focus is on routinization rather than the creation of shared knowledge'' where sharing knowledge from the ''subsequent implementation phase is primarily associated with maintaining production quality over the long term''. However, questions remain: how does the entrepreneur know when the ''long term'' is being disrupted by competing designs? Where is the feedback loop from the market that triggers a return to the sharing of knowledge prior to process design? From innovation to exploitation to innovation? Few papers explore a more holistic view of knowledge sharing across iterative innovation lifecycles[6]. Datta (2007) forwards a Knowledge-in-Motion model to capture the cycles of exploration and exploitation as organizations use software and human agents to a cyclical transformation of data-information-knowledge-creativity-innovation-data.

While more work is needed for expounding the feedback loops that underpin knowledge lifecycles, the research community and practitioners alike would benefit from a better understanding of environmental uncertainty and performance tradeoffs. The above projects were conducted in a relatively stable environment when compared to other ''hypercompetitive'' environments such as semiconductors and pharmaceuticals. By definition of Böhn's (1994) scale, the authors in essence measured shared technical knowledge as process quality. In the cases chosen for this study, raising the levels of technical knowledge did lead to the anticipated long-term benefits of process stability. Yet this strategy might be unwise in situations where product and capability lifecycles (Helfat and Peteraf, 2003) are short and gains from higher levels of technical knowledge are not realized.

For reasons of space and readability, this study has not attempted to deal with issues of learning style addressed by other authors (e.g., Armstrong and Mahmoud, 2008; Jablokow and Booth, 2006) and not easily manipulated by entrepreneurs. The present authors did not seek to uncover this intervening influence because, in addition, in most organizations the job screening is more related to one's education and demonstrated expertise rather than one's learning style. This is even more prevalent among non-professional technical employees.

On a final note, this research's limitations stem from its ambitious goal of attempting to converge structural and process elements, in order to examine the sensemaking that underlies knowledge sharing in entrepreneurial firms. From this perspective, some limitations are unavoidable. Could they be mitigated by future replication? The methods undertaken here were labor-intensive, especially the design of interview questions and the interpretation of answers. Exact replication of them in other data sites would be time consuming. Substituting a more streamlined approach might not serve as an exact replication, but would provide needed triangulation to assess our intriguing and unconventional findings. A greater degree of generality could be attained by adapting the above methods to other joint decision-making domains such as software development, as this might in time lead to a finer-grained analysis of common business activities viewed from a knowledge-based lens.

## Conclusions and future directions

The intricacies of knowledge sharing and transferring in entrepreneurial firms remain an important research topic as evidenced by the recent literature (e.g., Tsoukas, 2009). However, innovation without exploitation will probably not lead to successful EPD in the long term (e.g., Barr *et al.*, 2009). Eventually, ''the rubber must hit the road'' as the saying has it. For the entrepreneur, the dilemma is balancing time spent acquiring and integrating new knowledge from external sources versus encoding and transferring the resultant knowledge to internal firm members. This exploratory research comprised studying, in an entrepreneurial manufacturing firm, four contrasted product development projects with detailed qualitative data describing the sharing of knowledge during the technology transfer activities required. This was achieved by not just using the categorization of knowledge into levels by Böhn (1994), accepted in technological circles, but by extending it by developing a scale capable of matching the coding challenges of the current exploration of technical knowledge transfer. Four product-development projects served as the empirical case-based substratum used to qualitatively surface common patterns of knowledge transferring and sharing.

The detailed qualitative data collected contribute an insightful conclusion, one that sheds light on a little-noticed limitation of the accepted organic model. Comparing four projects in their latter stages of design and implementation, organizational complexity (as traditionally understood) did not generate higher levels of shared technical knowledge as expected in light of Hoopes and Postrel's (1999) well-known study of glitches in knowledge transfer. Interestingly, the more complicated and traditional plant did not pursue a goal of increasing late knowledge sharing, but rather sought to reduce the need for it by making the end process sufficiently robust. In contrast, the least complex and more organic plant consistently pursued knowledge sharing to compensate for its lack of formalized procedures.

The case study also offers grounds to question a view becoming dominant in organizational learning. It reveals that increases in laboratory experimentation during the early stages of a project may result in an extensive exploration of the design solution space. The implication is that, contrary to expectations, when learning-before-doing projects are carefully conducted, they can create (or at least entail) more knowledge sharing compared with learning-by-doing projects. Following Churchman (1968) and Nass (1994), an a priori explanation is that learning-before-doing renders the recipients more capable of learning from experience; in addition, by increasing the credibility of the knowledge source, it enables smooth knowledge transfer to other recipients in an entrepreneurial firm.

Another explanation lies in the construction of organizational routines (Nelson and Winter, 1982) as patterns of collective interaction behavior, followed repeatedly so as to build on and institutionalize best practices. The serendipity of learning-by-doing relies on idiosyncrasies and chance – not a sure-fire strategy. A safer one entails planning and building routines *ex ante*, which requires inculcating patterns systematically informed by learning-before-doing. In spite of its positivist undertones, our research rekindles the promise of the cognitive perspective in knowledge sharing; it does so by providing greater detail on the synthetic categories of replication and adaptation found in the literature (e.g. Williams, 2007).

In conclusion, as a way to glean richer insights on knowledge sharing and transfer, future research may find it useful to examine knowledge sharing beyond Shannon and Weaver or Szulanksi to examine knowledge sharing from the cognitive sciences perspective. Over the years, cognitive science has built a vast taxonomy of conceptual metaphors and figurative expressions to create rich, transferable abstractions that embody complex knowledge (e.g., Lakoff, 1990, Fauconnier and Turner, 2003). Given that organizational communication is steeped in syntax and semantics that underpin knowledge sharing, contemporary research on linguistics and cognition might offer a useful bridge to gaps in knowledge ontologies.

In spite of questions that remain for future research, entrepreneurial firms will find the results offered here interesting and complementing the general view on knowledge sharing. Despite the claims of the popular press, it may not be just the sharing of knowledge that influences performance, but rather the appropriateness of it. Entrepreneurial firms that equate knowledge sharing to success may be myopic: at least as revealed by this study, support for it is inconclusive. Managers would be misguided to rush to apportion too much time and effort to the affective rather than the technical aspects of knowledge sharing. Unless entrepreneurial firms can match and meld the appropriate mix of people, efforts at knowledge sharing may fall short of delivering optimal results – and may thus render knowledge an increasingly elusive asset.

## Notes

1. Hoopes and Postrel (1999) did not address the problem of measuring knowledge directly; instead, they developed a scheme for correlating absence of shared knowledge to product development failures.
2. While the context of this study is knowledge sharing, our case study deals with ''technical'' knowledge sharing. The authors feel that technical knowledge is more appropriate because it is more difficult to share and offers deeper insights into the mechanics of entrepreneurial knowledge sharing for product development performance.
3. These ''knowledge architects'' remarked that the knowledge tree diagrams could be useful for future projects requiring knowledge transfer.
4. Because of the number of exhibits already appended to this paper, the results for projects Gamma and Delta have not been included here, but would be made available on request.
5. The term ''common knowledge'' refers to knowledge held by two or more individuals that is not necessarily being communicated by one person to the other (Hoopes and Postrel, 1999). Much of the idiosyncratic resultant shared knowledge is likely to become knowledge common to longstanding project participants.
6. The authors thank Reviewer 2 for these insightful comments.

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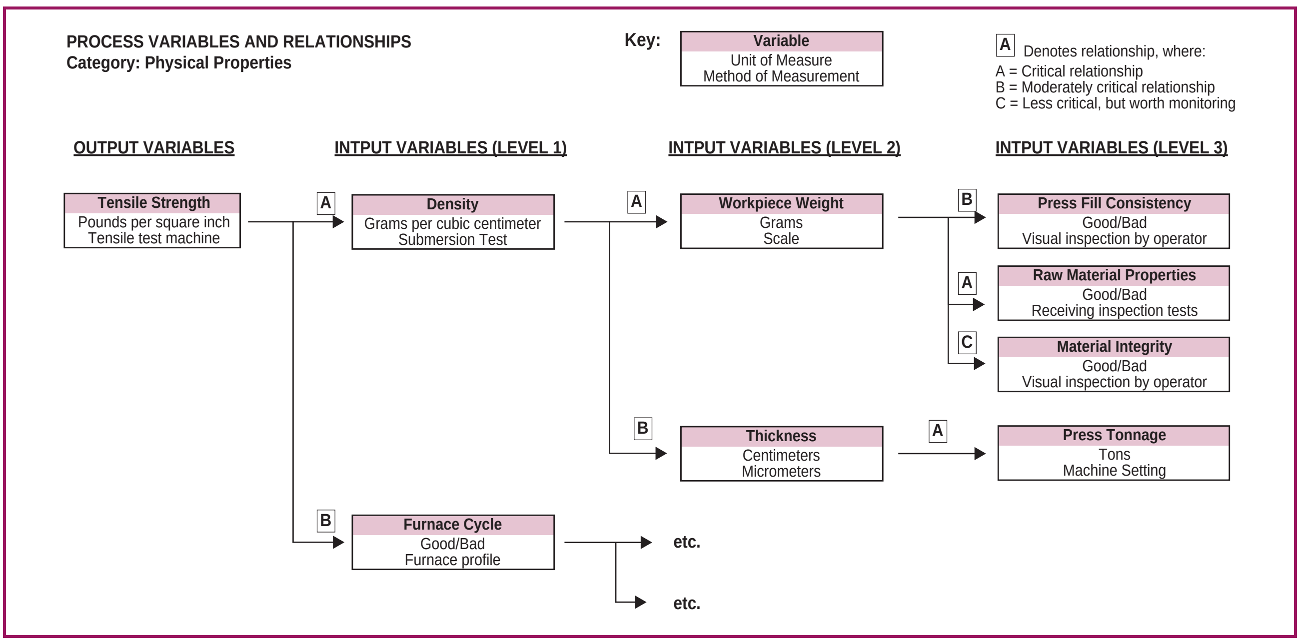
## Appendix

**Figure A1** Sample knowledge tree diagram



## About the authors

Alan T. Burns (BS Mech. Engr., General Motors Institute; MBA and PhD in Administrative Science, Kent State University; Juris Doctor, DePaul University) is the Chair of the Graduate Business Department at the Chicago campus of Argosy University. He has worked in the corporation world and academia for over 25 years, having held a variety of management, technical and professorial roles. His areas of expertise and research interests include knowledge management, business education, information technology, intellectual property, business strategy and organizational development. His teaching portfolio includes over 25 courses in business, technology and law. Alan T. Burns is the corresponding author and can be contacted at: atburns@argosy.edu

William Acar (Dipl. Ing.; MASc. Waterloo, CA; PhD Wharton-Upenn, USA) teaches Management and Information Systems at Kent State University. The author of numerous published articles, he is the initial author of the CSM causal mapping method for the analysis of complex business situations and related a book titled *Scenario-driven Planning*. Currently, his method is being used to develop a computerized GSS for solving strategic and organizational learning problems. He has also developed measures of diversity better calibrated than the Herfindahl index and the entropy function. He has published in journals such as: *Strategic Management Journal*, *Journal of Management Studies*, *INFOR*, *Decision Sciences*, *OMEGA*, *Journal of Management*, *Information Systems*, *European Journal of Operational Research*, *International Journal of Operational Research*, *Systems Research*, *Behavioral Science*, *FUTURES*, *International Journal of Organizational Analysis*, *International Journal of Technology Management*, *Production & Inventory Management*, *Strategic Change*, *INTERFACES* and the *International Journal of Commerce & Management*.

Pratim Datta is a Farris Family Research Innovation Fellow (2009-2012) and faculty at the College of Business with an interest in MIS and global supply chains. He has over 45 publications in journals and conferences. He is placed among the top 40 researchers publishing in top information systems journals, internationally. His research looks at knowledge management, global technology and supply chain management in areas of user experience, design, security, and deployment. His work has been published in prestigious journals such as the *Journal of the Association of Information Systems, Knowledge Management Research and Practice, Information Systems Journal, European Journal of Information Systems*, among others. He has four patent applications in the areas of biometrics authentication, electronic voting, and green solutions. Prior to joining academia, he held consulting and project management positions for eight years in multinational companies. He teaches MBA, EMBA, and PhD courses.