LEARNING AT THE BOUNDARY OF THE FIRM: LEARNING-BY-INTERACTION BETWEEN A MANUFACTURER AND ITS USERS

by

SUNG JOO BAE

B.B.A. Business Administration
Yonsei University, 2000

M.S. Information Economics, Management and Policy
University of Michigan - Ann Arbor, 2004

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Signature of Author: _____
MIT Sloan School of Management
April 13, 2009

Certified by: _____
Eric von Hippel
Professor of Management
Thesis Supervisor

Accepted by: _____
Ezra W. Zuckerman Sivan
Associate Professor of Strategic Management and Economic Sociology
Chair, PhD Program, Sloan School of Management

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Abstract

My dissertation centers on the very nature of the interaction and the learning that happens between users and manufacturers, and explores various micro-level mechanisms, which I call, "learning-by-interaction." The core concept, learning-by-interaction at the boundary of a firm, challenges the conventional perspectives – unidirectional and iterative – that failed to recognize the interactive learning process that happens between a manufacturer and its users. At the center of collaborative development of new products lies the issue of a language problem. When manufacturer and its users are engaged in the new product development process, they will naturally speak different languages. Investigation into the communication between seemingly disparate groups – a manufacturer and its users – reveals that the language boundary can be mitigated by local coordination based on the technical interdependencies between user requirement and technological implementation.

Chapter 2 initiates this discussion by laying the foundation of the phenomenon. By reviewing the extant literature on firm boundaries, I extract relevant mechanisms in which the user-manufacturer boundary can be better designed. The language-oriented perspective is then presented as the main perspective of this dissertation. By conducting an exploratory study at a financial services firm, Fidelity Investment, I identify a long tail

of the users' language diversity. This indicates that a substantial amount of commonality and a substantial amount of diversity coexist among the users.

Chapter 3 extends what we know about firm boundaries from the existing theories and empirical findings, and focuses on a specific type of collaborative product design process between a manufacturer and its users. By using the grounded theory building method with multiple data sources from a manufacturing company in Canada, I develop a process model of how user-manufacturer problem-solving language differences can negatively affect the collaboration. Then the discussion shifts towards the actual process of how the language boundary can be mitigated by local coordination based on the technical interdependencies between user requirement and technological implementation.

In Chapter 4, I identify the learning-by-interaction process between a manufacturer and its users in the product development stage. By examining 359 user-manufacturer co-development projects, I demonstrate that a focal manufacturer and its users have a learning curve identical to that observed within the boundary of the firm. But in contrast from what the traditional learning-curve effect suggests, I show that this learning-by-interacting with users benefits the design process rather than the manufacturing process. To understand the process of learning-by-interaction more deeply, I analyzed 2,365 communication data consisting of emails and phone call records and found that the timely and responsive feedback of interdependent information is critical in continuous-design problem-solving in this user-manufacturer learning process. The effects of prior templating – problem-solving with the products used against the use context - and distance – both spatial and temporal - on learning were examined as well, but it was revealed that they did not have a significant role in the context of this field study.

Thesis Supervisor: Eric von Hippel
Title: Professor of Management

Thesis Committee:

Eric von Hippel (Chair)
T. Wilson Professor of Management
MIT Sloan School of Management

Stefan H. Thomke
William Barclay Harding Professor of Business Administration
Harvard Business School

Thomas J. Allen
Howard W. Johnson Professor of Management, Emeritus
MIT Sloan School of Management

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In 2007, I visited the Kono District in Sierra Leone for two weeks. It was one of the most remote places I had ever visited, far removed and vastly different from everything that I had known in my life. At the same time, my trip provided me with the chance to think about my current life at MIT. What I realized then was that one can only truly realize what he is facing when he can take a step back from that life. Now that I have finished my dissertation and all other requirements for graduation, I have come to acknowledge how much I owe my whole doctoral study to the people surrounding me. Even if I didn't have any chance to thank them one by one during my study, I would like to thank everyone who supported and cared for me in Ann Arbor and in Boston.

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I hope that this study and my future study following this dissertation can contribute to the understanding of the business world and more broadly, our society.

CHAPTER 1: INTRODUCTION

Innovation happens both within and outside the boundary of a firm. The former has been the main focus of management study for decades, while the latter is getting more and more attention from both practitioners and scholars alike. The main driver of this shift towards the innovation that is taking place outside the boundary of a firm is the effectiveness of communication in the new networked era that connects and empowers users.

However, many firms struggle with the issue of how to connect to the right people in the right way. Since the innovative activities that happen outside a firm are often free from a firm's influence, being able to connect to those activities that can be of great value to the manufacturer's own innovation is a very challenging task.

My dissertation centers on the very nature of the interaction and the learning that happens between users and manufacturers, and explores various micro-level mechanisms, which I call, "learning-by-interaction." The core concept, learning-by-interaction at the boundary of a firm, challenges the conventional perspectives – unidirectional and iterative – that failed to recognize the interactive learning process that happens between a manufacturer and its users. By understanding the nature of learning that involves those inside and outside a firm, and by tapping into the joint problem-solving practices in this area, it is possible to understand and better manage the micro process of collaboration that can extend the learning-by-doing beyond an organization's boundary. In this dissertation, I view users as valuable sources of knowledge that can be incorporated into a firm's own learning process, rather than seeing users as separate entities outside of a firm's boundary.

At the center of collaborative development for new products lies the issue of a language problem. When a manufacturer and its users are engaged in the new product development process, they will naturally speak different languages. In this dissertation, I use the basic notion of scientific and engineering problem-solving to explain how this language difference can be mitigated by local trial-and-error learning. What is important in this process is that the information that has to be transferred is limited and bounded by the interdependency that exist between the two parties involved in the joint problem-solving. Investigation into the communication between the seemingly disparate groups – a manufacturer and its users – reveals that the language boundary can be mitigated by local coordination based on the technical interdependencies between user requirement and technological implementation.

In the actual problem-solving situation, technical interdependency between the user requirement and the final product as the technical outcome plays an important role in generating the local trading zone. At the same time, the technical interdependency provides a venue for two disparate groups of people – in the field study setting, mechanical engineering-oriented manufacturer and electrical engineering-oriented users of the focal manufacturer – to engage in the joint problem-solving.

Chapter 2 initiates this discussion by laying the foundation of the phenomenon. By reviewing the extant literature on firm boundaries, I extract relevant mechanisms in which the user-manufacturer boundary can be better designed. The language-oriented perspective is then presented as the main perspective of this dissertation. By conducting an explorative study at a financial services firm, Fidelity Investment, I identify a long tail

of the users' language diversity. This indicates that a substantial amount of commonality and a substantial amount of diversity coexists among the users.

In Chapter 3, I present a qualitative study that examines the language difference between a manufacturer and its users, and its consequences in the new product development process. This study focuses on the nature of the language difference between users and manufacturers and explains how such differences can be mitigated by a local trial-and-error learning. Key to this process is recognizing that the information that needs to be transferred is limited and bound by the interdependencies between the two parties involved in the joint problem-solving. Investigation into the communication channel between the seemingly disparate groups – a manufacturer and its users – reveals that the language boundary can be mitigated by the local learning process based on the technical interdependencies between user requirements and technological implementation.

In Chapter 4, I identify the learning-by-interaction process between a manufacturer and its users in the product development stage. By examining 359 user-manufacturer co-development projects, I demonstrate that a focal manufacturer and its users have a learning curve identical to that observed within the boundary of a firm. But in contrast from what the traditional learning-curve effect suggests, I show that this learning-by-interacting with users benefits the *design* process rather than the *manufacturing* process. To better understand the process of learning-by-interaction, I analyzed 2,365 communication data consisting of emails and phone call records. I found that the timely and responsive feedback of interdependent information is critical in continuous-design problem-solving in this user-manufacturer learning process. The effects of prior templating – problem-solving with the products used against the use context - and

distance – both spatial and temporal - on learning were examined as well, but it was revealed that they did not have a significant role in the context of this field study. The result is then discussed to show how this study can contribute to the current literature on dynamic capabilities and organizational learning. I conclude this chapter with a discussion of the direction for future research.

Chapter 5 presents a new line of thinking in bridging the gap between a manufacturer and its users – the creation of a new language scheme. Drawing from the literature on innovation toolkit and trading zone, I try to generalize some observations made in four different cases of new language creation.

Chapter 6 concludes this dissertation with the implications of the current research and the direction for future research.

* * * * * * * * *

The main motivation of this research stems from three different perspectives. First, I have been fascinated by the phenomena of more and more firms trying to incorporate user-driven innovations and creative community activities that are happening outside the firms' boundaries. For example, Lego is changing their product development strategy so that it can harness the various design capabilities of the users. Lego developed the new Lego Factory product to specifically allow users to design their own product. The company not only benefits from the various designs users create, but also benefits from

selectively choosing the good designs based on other users' evaluations. This example illustrates that firms are breaking down their traditional boundaries towards users thanks to the decreasing cost of communication, increasing modularization, and emerging flexible production systems, just to name a few reasons. Studies focusing on the interface, the interactive problem-solving, and the learning process that takes place between a firm and its users will be an increasingly more interesting area for both scholars and practitioners alike.

Second, existing studies tend to focus on intra-firm and inter-firm collaboration while leaving much room for exploration of the focal space between a firm and its users. Existing views on their interaction are unidirectional or iterative, neglecting the possibility and importance of interactive and progressive learning in this space and the conditions in which learning can be more efficient.

Finally, my current research stream is also motivated by my personal experience. During my career at IBM and as a co-founder of a new start-up company, I came to acknowledge that people in consulting and the software business tend to underestimate the amount and value of learning that comes from customers. As a part of IBM's software development team, I realized that problem-solving does not end at the product development stage, but almost always continuously flows to the user side. I also recognized that actively engaging users, both efficiently and effectively, is a vital part of successful product development projects.

I study this phenomenon with unique datasets I gathered from various field studies. In order to understand this changing nature of interaction between a manufacturer and its users, I look closely at the boundaries of a firm where these interactions actually take

place. Many different methods were employed - such as interviews, quasi-experiments, quantitative analysis, and verbal protocol analysis - to understand this phenomenon better.

CHAPTER 2: USER-MANUFACTURER BOUNDARY

2.1. Introduction

It is difficult to imagine people in manufacturing companies working directly with users of their products. Physically, users are usually distant from the manufacturer. Once the product is in the market, the engineer at the manufacturing company and the product users seldom communicate with users. On the other side, users don't share the history of the technological development within the firm. Considering all these preconditions, it seems that it is almost impossible for a manufacturer to successfully coordinate any collaborative activity with its users. Yet, we see more and more examples of companies successfully reaching out to the users of their products and services in various capabilities. For example, IBM, along with many other software companies, is trying to tap into the creative forces of open source communities. Innocentive is trying to capture the problem-solving capabilities of distributed users. Threadless is trying to capture user's creative design capabilities. Companies like IBM are now seeing such efforts producing successful results. There is a recognition that working more closely with users is not only possible, but it can also bring positive results to a firm's main activity – research and product development.

There is an oxymoron in the previous paragraph – a permeable boundary. In some sense, there is a strong boundary between a manufacturer and its users. I will examine what constitutes this boundary in the following section. There is also the possibility of permeating this strong boundary by connecting distant users to the focal firm. I will

discuss the existence of this permeation in the following chapter, and examine various micro-mechanisms that enable this permeation.

Understanding the nature of this boundary between a manufacturer and its users, and examining whether this boundary can be breached will be the main research question for my thesis. In this chapter, I present an explorative empirical study that examines the user-manufacturer boundary. This study will shed some light on the nature of the boundaries that exist between a manufacturer (in this case, a financial services firm) and its users.

Boundaries have been one of the most important areas of inquiry in management studies. However, user-manufacturer boundaries have not received great attention in this field. Before I move on to the empirical examination of this phenomenon, I will lay out management scholars' perspectives on the various types of boundaries and how they relate to the user-manufacturer boundary.

2.2. Literature Review on Different Perspectives of Boundaries

Many different sub-disciplines of management studies have explored the issues of firm boundaries. The basic question was why a boundary of a firm existed. Then, discussion moved on to the nature of the boundary and the different ways it can be managed. In this chapter, I will discuss the different perspectives on firm boundaries. They are:

Task-oriented perspective

Information-processing perspective

Transaction-cost perspective

Knowledge-based perspective

Technology-oriented perspective

Language-oriented perspective

As examined below, these perspectives provide an insight into the various boundaries that exist within or outside of the firm.

2.2.1. Task-oriented Perspective

The notion of a firm's boundaries stems from the observation that a firm is an entity within a larger system. In this regard, conceptualizing a firm as an open system provided an important step in the theorization of a firm's boundaries (Katz & Kahn, 1966).

Behavioral theories of a firm conceived organizations as open systems (March & Simon, 1958), recognizing the uncertainty and complexity imposed by their environment. Another relevant inquiry that scholars in this school of thought pursued was how these factors *outside* the boundary of an organization affected the decision making *within* the boundary of the organization. Lawrence and Lorsch (1967) further developed the concept that organizations have different structures to respond to different environmental contingencies. For example, firms in more complex environments were more likely to have highly differentiated structures and concentrated on coordination, whereas firms in less complex environments were less differentiated and more integrated.

In this conceptualization of an open system, organizations set up boundaries in order to deal with environmental uncertainties. While Lawrence and Lorsch (1967) as well as Burns and Stalker (1961) were explaining the variation among different organizations, Thompson (1967) contributed to this line of thinking by explaining the variation within an organization. According to his view, there are three distinctive components within organizations: production, managerial, and institutional. In order to buffer production – known as the 'technical core' - from uncertain and complex environmental influences, institutional units are placed outside to cope with suppliers of resources, markets, and other agents. Managerial units are placed between institutional units that track and deal

with environmental changes, and the technical core carries out day-to-day routine production activities.

Thompson (1967) also made another important contribution on a more micro level. By incorporating the concept of task interdependency, he argued that the activities within an organization should be organized based on the degree of task interdependency: pooled, sequential, and reciprocal interdependency. This notion of task interdependency explains why and how the boundaries are determined within an organization – i.e. among sub-units of an organization. When task interdependency is low, two sub-units can be disjoined while maintaining loose coupling with the supra-unit (pooled). If the output of one unit is the input for another unit, then the two units can be joined based on this input-output relationship (sequential). But if the task interdependency is very high and reciprocal, the two units should be considered for integration (reciprocal). This line of thinking based on task interdependency influenced many of the following perspectives on firm boundary, providing the basic reasoning behind the interrelationships between two units of an organization.

According to this conceptualization, the periphery of an organization that deals with the users can be seen as the institutional unit that keeps the technical core from the users. In fact, opening up the technical core can be a quite risky strategy since it will overburden the technical core with great uncertainty. This uncertainty may come in the form of changing user requirements and requests, which will guide the technical core's main function of development and production.

However, this perspective somewhat downplays the feasibility and increasing availability of user-manufacturer interaction and collaboration. Users are often the main

sources of innovation. Working with users will bring new ideas that were not available within an organization – ideas that may not be generated among the organizational members over the course of their collaboration. In this sense, the uncertainty that was conceptualized as something that should be kept away from the technical core can be in fact an important source of information and innovation that the technical core should be aware of. Having institutional and managerial units for buffering might hinder the constant and direct flow of information from the users, even distorting the information.

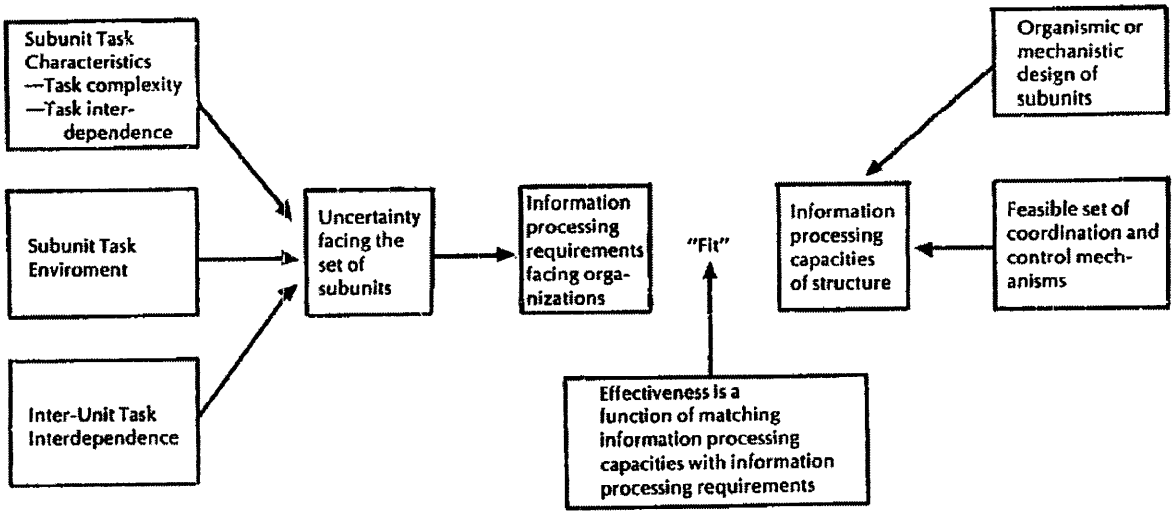
2.2.2. Information-processing Perspective

The information-processing (IP hereafter) perspective views organizations as complex information processing systems and lays out the detailed activities and structures of organizations (Galbraith, 1973; Huber, Oconnell, & Cummings, 1975; Tushman & Nadler, 1978). The IP perspective was heavily influenced by the behavioral theory of a firm (Cyert & March, 1992; March & Simon, 1958) and Thompson's conceptualization of an organization (Thompson, 1967). Therefore, this perspective is tightly related to the previous task-oriented perspective. In the IP perspective, the information-processing activities across the boundary of the firm are highlighted to shed light on how organizations function and set the boundary around and within them.

There are several key concepts and relationships that emerge from this body of literature. First, an organization is viewed as an entity that communicates and interacts with the environment. In this sense, organizations are regarded as open systems (Thompson, 1967). Therefore, the environmental uncertainty becomes a very important

factor in designing the organizational structure that responds to its surrounding (Tushman & Nadler, 1978). Second, task characteristics are also very important. For example, task variety and task analyzability were identified as the basic concepts that can relate to structure and process (Hage & Aiken, 1969; Perrow, 1967). Task interdependence is also identified as an important task characteristic since it introduces uncertainty due to the complex task structure. Third, the notion of information is also important as is evident from the name of the theory. Task characteristics are sometimes related to the amount and the equivocality of the information (Daft & Macintosh, 1981). Some tasks need more information processing while some are more difficult to accomplish because the information conveyed in the tasks cannot be easily interpreted. With all the concepts and their relationships in mind, organizations can be viewed as information processing systems that are constantly gathering, interpreting, and synthesizing information in the context of decision making (Tushman & Nadler, 1978).

Figure 2.1 Information Processing Model (Adapted from Tushman & Nadler, 1978)



The environment is generally seen as a source of uncertainty since the areas outside an organization are not under its control and are potentially unstable (Thompson, 1967; Weick, 1979). Research on organization studies identified several dimensions of environmental uncertainty (Jurkovich, 1974). In particular, studies revealed that the static/dynamic dimension was an important aspect of environmental uncertainty: the more dynamic the change in the environment, the greater the uncertainty faced by the organization (Duncan, 1972).

In an uncertain environment, information processing activity should also reflect the information requirement that arises from the uncertain environment. For example, organizations facing a stable environment can develop rules or standard operating procedures to deal with their environment. But in a changing environment, fixed rules and routines will not be able to deal with the substantial environmental uncertainty (Tushman & Nadler, 1978). Organizations must deal with the uncertainty by searching

for more information from the environment. Galbraith (1977) argued that variations in organizing modes are actually variations in organizations' capacity to process information and make decisions about events which cannot be anticipated in advance. In his view, organizations are not autonomous and cannot survive just on information generated from inside. Information should also be extracted from the external environment, processed in a variety of ways and disseminated throughout organizations. In some cases, information from *environmental scanning* could be used as the important information source for strategy formulation and decision making (Daft & Weick, 1984) that sets up directions for the organizations. But in general, information seeking activities from outside the organizations are related to the levels of environmental uncertainty: when there is more uncertainty in the environment, organizations can dissipate this uncertainty via more active information seeking. (Lawrence & Lorsch, 1969b).

One way of scanning the environment is to use boundary spanning roles. This comes from the idea of intermediary roles which serve to link organizations with relevant, potentially influential segment of their environments. These connecting roles are seen as informational: they gather data, information, ideas, opinions, market information, competitor activity, and numerous other matters of interest to their organizations (Allen, 1977a; Ancona & Caldwell, 1992; Tushman, 1977). Even though the external information inputs of large multinational organization may not depend solely on the efforts of boundary spanning individuals, the notion of people being directly involved in the information gathering and disseminating stages is still valid and should be considered carefully when we study the organization as the information processing system. After all, much of the informal information exchange is often done by the gatekeepers.

Task characteristics have been an important concern to scholars who study organizational design and structure (Perrow, 1967). More specifically, organizations were conceptualized in terms of their technologies; that is, they were seen primarily as systems for getting work done and for applying techniques to the problem of altering raw materials. Perrow identified two specific aspects of technology: the number of exceptional cases encountered in the work (*task variety*) and the nature of the search process undertaken when exceptions occur (*task analyzability*). Low task variety means that participants experience considerable certainty about the occurrence of future activities; high variety means that participants typically cannot predict problems or activities in advance (Daft & Macintosh, 1981). When a task can be analyzed, participants typically follow an objective, computational procedure to resolve problems. But, when a task cannot be analyzed, participants may have to spend time to think about what to do, discuss the issue with other colleagues, and search for solutions beyond normal procedures. From these two dimensions, four general categories of work activities were identified – craft, engineering, nonroutine, and routine technology (Perrow, 1967).

In one way or another, task characteristics have been conceptualized to be linked to environmental uncertainty. But scholars have neglected the very important relationship between task characteristics and environmental uncertainty. A fairly important but neglected question to be answered might be whether the task variety or analyzability causes the uncertainty, or whether the environmental uncertainty affects the task characteristics. In a real organization, these two different constructs –task characteristics and environmental uncertainty – interact with each other. That is, a stable and less uncertain environment pushes organizations towards more routine technology. But at the

same time, having routine technology reduces the uncertainty that individuals or sub-units have to face. Having this routine technology may even reduce the adaptability to cope with a radical environmental change (Anderson & Tushman, 1990, 1991; Tushman & Anderson, 1986).

As discussed in the task-oriented perspective, the notion of technology and its consequences in organizational structure and design was originally conceptualized through the observation of production technology (Thompson, 1967). But since the information processing view of the organization expands this idea to other kinds of organization as well, we have to assume that we now have to consider the whole spectrum of different technology used in different parts of the organization. For example, a production line might be a fairly routine technology whereas a R&D sub-unit could use a more non-routine technology. In sum, organizations consist of many different tasks, some of which can be categorized into more routine tasks, whereas some of them can be categorized into more non-routine tasks. At the same time, organizations also face different environmental changes over time – stable or dynamic. Therefore, when we conceptualize task characteristics into the research design, we also have to consider the environmental uncertainty.

Task interdependence is another factor that can be associated with uncertainty. If one's task is changed so that it is dependent upon the work of another, the need for joint coordination and problem solving increases, therefore the amount of work related to uncertainty can be increased (Tushman & Nadler, 1978). Task interdependence can be observed both on the individual and the subunit level (Thompson, 1967; Weick, 1979). Thompson provided a classification of the different types of interdependence that might

characterize relationships among sub-units. In order of increasing complexity, the types of interdependence were identified as pooled, sequential, and reciprocal. Some empirical studies (Van de Ven, Delbecq, & Koeig, 1976) showed partial evidence to support the relationship between the type of interdependence and problem solving complexity.

Compared to traditional information studies which concentrated on the physical characteristics of information and the mechanics of its transmission (Shannon & Weaver, 1949), organizational theorists concentrated on the consequences of that transmission, which eventually involve the alteration of the mental representation held by the information receiver (Daft & Macintosh, 1981). In this sense, information is regarded as the sub-set of data that affects a change in an individual's understanding of reality. From this conceptual framing, scholars in organization theory came up with many different dimensions of information.

First, information amount is *the volume or quantity of data about organizational activities that is gathered and interpreted by organization participants* (Daft & Macintosh, 1981). Most studies support the notion that a variety of tasks is associated with greater information processing and that a wide range of problems tends to be covered in high-variety settings. Therefore, a wider scope of information has to be shared and more people have to be involved. All these factors connect the task variety with the larger amount of information.

The second variable in organizational information processing is the equivocality of information (Weick, 1979). Weick shares the notion of an organization as an information processing system, but his focus is more on the equivocality of the information rather than the amount of the information. He used many anecdotes in his book, "The Social

Psychology of Organizing," that can illustrate his point on this matter; one interesting example is how a policeman could come out of a dangerous situation created by a group of people by making a very equivocal situation for the crowd. This equivocality made the crowd take time, talk to each other, and make sense of the situation, and as a consequence the cop escaped the dangerous situation. The equivocality comes from the fact that the policeman's remarks can be interpreted in various ways, which, in turn, makes the task of interpreting the situation a little more difficult. Information equivocality is defined as *the multiplicity of meaning conveyed by information about organizational activities* (Daft & Macintosh, 1981). It is found to be related to one of the task characteristics: task analyzability. If a task can be analyzed, then precise information can be produced, therefore the measurement of task activities, as well as rules and procedures, will be specific and accurate. Daft and Macintosh (1981) found some empirical results, which resonate well with previous research on this topic. Task variety was related to the information amount and task analyzability was related to the information equivocality. But at the same time, compared to the unanalyzable tasks, analyzable tasks created more quantitative information, which, in turn, increased the amount of information.

For the boundary between a manufacturer and its users, this perspective adds an interesting area of consideration. From the perspective of information processing, it is important to notice that what matters is the fit between the nature of the information processing requirement – often decided by the task characteristics - and the structural information processing capacities. In this line of thought, the boundary between a manufacturer and its users should be also managed by the fit between the information requirement and the structural capacities.

However, the information processing requirement and processing capacities of user-manufacturer boundaries change both over time and over the manufacturer and the users' cumulative experience (jointly and individually). Users know what product specifications they want from the manufacturer as they have more information on what the manufacturer can provide. Thus, users' requirements are usually clarified after some period of interaction. Manufacturers can also figure out how users think and what they want over a cumulative joint experience. How to design firms to cope with this changing information capacity requirement is the main issue at user-manufacturer boundaries.

If we consider the flow of information at the user-manufacturer boundary as being unidirectional, then the uncertainty in users' requirements – how clear the users are about what they want in the product or services – will be the main factors in designing the boundary. In this case, firms should design the user-manufacturer boundary according to the changing uncertainty. In the early stage of interaction with users (e.g. early stages of new product development), manufacturers can initiate a more direct contact. When they build more experience with users, the boundary can be managed with a more automated toolkit approach. Users can then use a design toolkit and engage in the product design themselves (Thomke & von Hippel, 2002). I will discuss this possibility in detail in Chapter 5.

Since the flow of information at the user-manufacturer boundary is not always unidirectional, there is a lot of information that users would receive during the product development process as well. This means that the design of the user-manufacturer boundary is most critical when there is great uncertainty about the product or service features. According to the basic premise of the information processing perspective, the

user boundary should be designed in a way that the information from the environment (in this case, from the users) should be pursued. In this process, various informational characteristics should be considered – e.g. task variety, task characteristics, and task interdependence.

There is one caveat to taking this perspective at the user-manufacturer boundary level. Those informational characteristics mentioned above are not easily identifiable *ex ante*. On the one hand, this is due to the fact that there are problem-solving processes between a manufacture and its users which gradually shift the uncertainty from an ill-structured design space to a well-structured design space (Simon, 1973). On the other hand, the uncertainty can be seen as being inherent in the product development process. It is impossible to predict the uncertainty level *ex post,* analyzing what happened during the product development process, but it is quite impossible to predict all the possibilities before it actually happens. Therefore, designing the firm's boundary and expecting to know all the possible informational characteristics can be quite challenging, if not impossible. One alternative is to design the boundary flexible enough to deal with any uncertainty that can arise during the course by letting engineers at the boundary to directly interact with the users. I will discuss this possibility in Chapter 3 and 4.

2.2.3. Transaction Cost Perspective

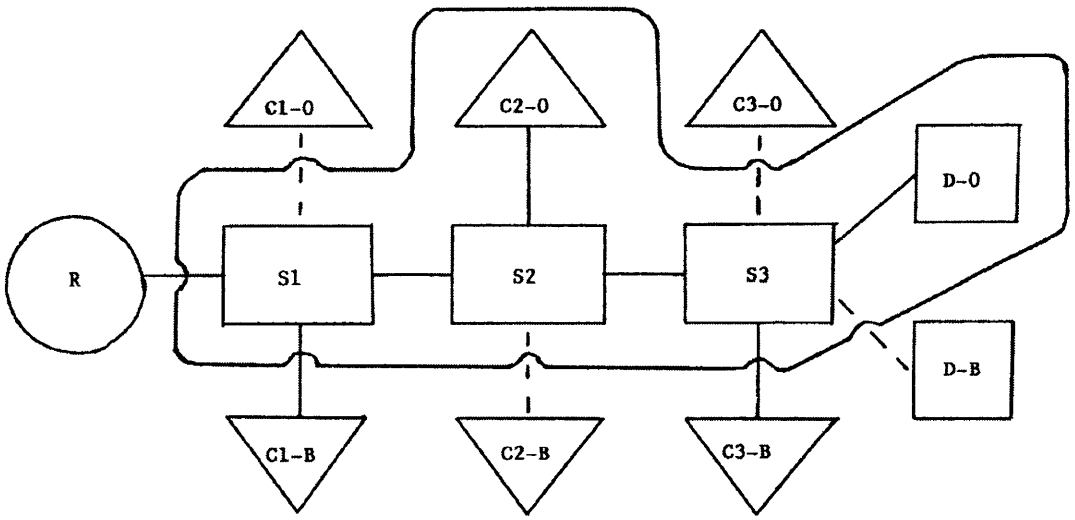
One of the old traditions of research on firm boundary issues was to take an economics-based approach. Transaction Cost Economics (TCE hereafter) attempts to answer questions on what conditions, firms (hierarchies) other than market mechanism

are better at the efficient governance of economic activity (Coase, 1937; Williamson, 1975). From this perspective, the costs of market governance increase (1) when the uncertainty of contracts increases, and (2) when there has to be an investment in transaction-specific assets. These are assets invested to achieve proximity of location for efficiency in transportation and inventory (site specificity), to achieve production efficiency through specialized technology (physical asset specificity), and to attain highly skilled individual in learning-by-doing (human asset specificity). Assets invested in routines or workflow for transaction (procedural asset specificity) were also found to be important in a later study (Zaheer & Venkatraman, 1994). Investment in these transaction-specific assets can bring a significant cost to the focal firm, especially when the contract should be altered.

TCE focuses on this transaction cost in a firm's decision to move its boundaries, leading to either a make or a buy decision of related components in production. When conditions surrounding the contract are too complex and uncertain for trading entities to understand and articulate *ex ante*, renegotiation has to occur in order to cope with the contingencies that arise over time. But this renegotiation can cause trading entities some problem, known as the "ex post small numbers opportunism." (Williamson, 1975) This is especially true since the investment in transaction-specific assets cannot be easily transferred to other uses. In this case, the focal firm is in a vulnerable position since the trading partner can easily require renegotiation of the contract terms, which Williamson call 'opportunistic behavior.' Therefore, in order to avoid this problem, firms decide to use hierarchies rather than a market transaction. Klein, Crawford, and Alchian (1978) explained this boundary rationale in a General Motor's case, showing that GM's decision

to acquire Fisher Body followed the transaction-cost-economizing explanation of a firm boundary decision.

Figure 2.2. Efficient Boundary in Transaction Cost Perspective (Redrawn from Williamson, 1981)



S1, S2, S3 – core production stages

R – raw materials

C1-B, C2-B, C3-B – component supply through 'buy' decision

C1-O, C2-O, C3-O – component supply through 'make' decision

D-B – distribution through market

D-O – distribution through firm's own distribution channel

Solid line – actual transaction

Dotted line – potential transaction

In an attempt to explain the organizational boundary shift, TCE fails to explain the technological details and their impact on the organizational boundary shift. In TCE's

economic rationalization of a firm boundary, production processes are viewed as sequential stages as depicted in Figure 2.2. In this figure, the closed curve that represents the effective boundary includes component C2-O and distribution unit D-O. C2 is internalized since it represents a more specialized component, compared to more standardized components. C1 and C3. C1 and C3 can be purchased from the market, whereas C2 needs an investment that can yield small-numbers-bargaining problem. Similarly, the decision to integrate forward into D-O depends on the fact that there specialized human assets are needed to sell and service the product. In this figure, the technical core (in Thompson's notion, 1967) is radically simplified by having several sequences of production stages. While this simplification makes TCE clean-cut and robust in explaining the shifts of organizational boundaries, it also poses the problem of not being able to explain technical changes at the component level that drives the boundary change (Murmann & Frenken, 2006). Why are C1 and C3 more standardized than C2 in the first place? What if a technical change breaks down component C2 into subcomponent C21 and C22, which are different in their degree of standardization? These changes affect the boundary decision and in turn are affected by the boundary change; but the transaction-cost account of boundary settlement is relatively silent about this issue.

In some sense, TCE adopts much of behavioral theory's view of an organization in that individuals are viewed as being "boundedly rational" compared to the pure rational assumption of neo-classical economics. Basic assumptions such as incompleteness of contracts and incompetence of individuals to handle large number of contracts all stems from this line of thinking.

There is a market mechanism between a manufacturer and its users. In terms of transaction, it is absurd to even think about bringing users into the hierarchy of the organization. However, idea sharing or collaborating with users is quite possible even by maintaining the market mechanism intact. The decrease of communication cost and the development of the technology enable the collaboration to be possible.

2.2.4. Knowledge-based Perspective

In a knowledge-based view, firms decide their boundary where they can successfully integrate specialized knowledge with respect to the market. Firms are not just task-fulfilling machines or information processing systems, nor are they mere transactional entities. Firms engage in generating and sharing knowledge (Kogut & Zander, 1992); hence their boundary decided by their effort to expand their knowledge-base (Grant, 1996). If the knowledge required in one production stage cannot be easily transferred to the following production stage due to tacitness (Polanyi, 1966) or situatedness (Tyre & von Hippel, 1997), these two production stages should be integrated regardless of whether the market is efficient in transferring a product from one stage to the next. Along the same line of logic, firms expand their boundary by making strategic alliance relationships with other firms that have the required knowledge for their survival.

If the boundary is decided by the locus of knowledge, locating where the knowledge resides in the organization is of critical matter. Building on the resource-based view of a firm (Wernerfelt, 1984, 1995), the knowledge-based perspective focuses on the question

of where the value of a firm comes from. In the knowledge-based perspective, values of a firm reside in well-established routines (Nelson & Winter, 1982) and capabilities to coordinate and combine its existing resources in a novel way (Teece, Pisano, & Shuen, 1997). In a similar vein, Leavitt and March (1988) indicated that knowledge is embedded in organizational routines and operating procedures, in its products and processes, in its technologies and equipment, in its layout and structures, and its culture and norms about how things are generally done.

But more importantly, knowledge resides in individuals, especially when the knowledge is tacit (Polanyi, 1966). Individuals develop new knowledge through everyday experiences. Individuals exchange information with other colleagues and learn from other individuals as well. Most of the studies on knowledge management assume that an individual is a key reservoir of knowledge. If we want to find out whether an individual is the repository of knowledge, we should look at the effect of turnover on organizational learning. A series of studies found that individuals are actually a very important source of organizational knowledge by showing the negative impact of turnover on performance (Argote, Epple, Rao, & Murphy, 1997). Various conditions under which turnover has different effects on performance have been also identified. For example, several studies found a positive effect of turnover on group or organizational performance (Virany, Tushman, & Romanelli, 1992). These studies analyzed more complex work settings involving scientists, engineers, and executives, and found that the complexity of the task affected individual knowledge. Another finding was that bringing new knowledge into the organization by hiring new workers will increase the overall performance for innovation-oriented, complex tasks. Although the specific details differ in these studies,

they all point to the important evidence that organizational knowledge resides in individuals.

Users possess important knowledge that manufacturers usually do not and cannot have detailed knowledge about the environment for product usage. Users also have the privilege to observe the products used in their specific use context. While this type of knowledge will be extremely useful for manufacturers, transferring it will require a special arrangement at the boundary. Knowledge-based perspective provides much rationale for why shifting the boundary toward the user side makes sense.

2.2.5. Technology-oriented Perspective

In this perspective, the organizational boundary corresponds to the technological boundary. Henderson and Clark (1990) stated that an organization's information processing structure mirrors the internal structure (architecture) of a product (p.27). Modular design of products leads to the loosely coupled organizational structure, leading to a more flexible organization that can respond to environmental changes (Sanchez & Mahoney, 1996).

Interdependencies are the core mechanism of this perspective. If one maps out the interdependencies among the technical components, one can also rationalize the mapping of the organizational structure corresponding to the technical architecture based on the fact that technical interdependencies are related to task interdependencies (Baldwin & Clark, 2000; Eppinger, Whitney, Smith, & Gebala, 1994).

In explaining the division of actual problem-solving tasks rather than the mere technical structure, von Hippel (1990) showed that it makes more economical sense to partition tasks based on the problem-solving activities for a specific technical component since problem-solving across technical boundaries will be costly.

Technological architectures evolve over time; therefore the task interdependence and corresponding organizational structure should evolve over time as well. Technical problem-solving has a progressive nature in that it involves defining problems, coming up with alternative solutions, and selecting one of those solutions (Frischmuth & Allen, 1969; Marples, 1961; Simon, 1973). This means that the organizational boundary has to shift accordingly.

When a manufacturer solely focuses on the technical interdependence and corresponding organizational structure, the interdependence between a manufacturer and its users may not a concern for this manufacturer. However, as I will discuss in Chapter 4, there is an interdependence between user requirements and the manufacturer's technical outcome. This interdependence also yields interdependent information that should be readily available during the joint problem-solving process. Therefore, the technology-oriented perspective provides a very important building block for how we should approach the user-manufacturer boundary. I will discuss it further in Chapter 4.

2.3. Language-oriented Perspective

Throughout this dissertation, I take a particular perspective in order to understand the boundary between a manufacturer and its users – *language-oriented perspective*. The basic assumption is that there is a language gap between a manufacturer and its users. This language difference creates a language transfer problem that should be resolved when there is need for direct or indirect collaboration between these two parties.

In the new product development (NPD) process, the language difference is critical in developing the products that successfully meet the users' needs. They should be clearly communicated to the focal manufacturer in order to come up with the product concept and design that matches the needs of the users (Ulrich & Eppinger, 2004). Even during the prototyping and testing stage, communication between users and a manufacturer continues in order to enable iterative problem-solving and to validate the result of product development in various usage environments.

Language difference comes from the difference in knowledge that users and a manufacturers have. Users reside outside the traditional boundary of a firm. Therefore, users are not directly involved in the learning-by-doing process through which manufacturers accumulate their technical knowledge (Arrow, 1962). This means that the experience that manufacturers gain in research and development of underlying technology as well as experience in manufacturing of the product is not shared by the users. Without the knowledge and expertise gained by the cumulative learning process, users often find it difficult to understand the inner workings of the technology that reside in the product offered.

Scholars in organizational study have viewed cross-boundary language problem in various ways, depending on the clarity of relationship between the signifier and the signified. The first view focuses on the transferring of understood meaning, assuming that the meaning is already specified (Carlile, 2004). This view, often termed as syntactic view, was in accordance with the information-processing view originated from Shannon and Weaver's transmission model of communication (1949). The basic assumption of this transfer model was that knowledge is explicit and can be codified; therefore, creating a one-to-one relationship between the signifier and the signified can be the solution to language problems. The relationship can be established through the creation of taxonomies and repositories of common lexicon (Davenport & Prusak, 1998) and standard operating procedures that provide basic means of information sharing (Nelson & Winter, 1982). Once these syntactic structures are in place, a language problem becomes more of an information-processing problem; therefore, how to design the organization to efficiently process information flow becomes the core question in these studies (Allen, 1977b; Galbraith, 1973; Lawrence & Lorsch, 1969a; Tushman, 1978).

The second view focuses on the semantic difference in which the relationship between the signifier and the signified is less clear and can only be understood by being placed in the same context. The lack of shared meaning originated from being embedded in different communities is the source of the language problem in this model (Lave & Wenger, 1991; Orr, 1996). Periphery members learn the language of their community and become a legitimate member, which Lave and Wenger termed as 'legitimate periphery participation.' Brown and Duguid (1991, p. 48) described this language acquisition process as follows.

> *Learners do not receive or even construct abstract, "objective," individual knowledge; rather, they learn to function in a community - be it a community of nuclear physicists, cabinet makers, high school classmates, street-corner society, or, as in the case under study, service technicians. They acquire that particular community's subjective viewpoint and learn to speak its language ... Learners are acquiring not explicit, formal "expert knowledge," but the embodied ability to behave as community members.*

Dougherty (1992) emphasized the role of different interpretive schemes used for understanding meanings. People in different departments form their own way of interpreting information. Thereby, they create departmental 'thought worlds' during the new product development process. For example, the same signifier 'development task' is interpreted with vastly different meanings based on each department's routines and way of interpreting new information. The technical people understand the development task as building the product, which is a real, hands-on, and physical process; the field (sales or customer relations) people view the same development task as developing relationships with customers, which is a ongoing, possible, and open-to-change process (modified from p. 188).

The third view is what Carlile (2002) referred to as the 'pragmatic' nature of boundary. A pragmatic perspective explains how the semantic difference can be intensified through situated reinforcement of meanings. Using the framework of semiotics, the pragmatic view focuses on the actual process of tying the signified and the

signifier together. This view shifts our attention to the particulars of what problem-solvers actually do in real problem-solving situations and the physical surroundings in those situations (von Hippel & Tyre, 1995).

Knowledge in this view is localized, embedded, and inseparable from practice. Dewey (1938) along with James (1963) laid the foundation of this view by establishing the basic characteristic of knowledge we should pursue: knowledge should be constructed by constant questioning current situations followed by the active engagement of individuals in shaping that environment. In this pragmatic view, it is crucial to transform the knowledge by creating new knowledge and validating it within and across boundary. In other words, providing a shared syntax and a way to bridge the semantic gap by a knowledge broker is not enough to reconcile the boundary problem. Since individuals invested in their acquisition of knowledge, other economic actors who want to adopt this knowledge should also invest in the learning, and transform their current habits to accommodate the newly developed knowledge.

This constant effort by individuals in the pragmatic sense not only provides the political milieu of how knowledge is embedded in the context, but also provides an important insight into how the language gap can be mitigated. What is important in this view is that it enables a process of transforming local, embedded, and invested knowledge into a common knowledge that transcends the boundary. As Carlile (2002) emphasized, it is critical to mitigate the knowledge gap for individuals (1) to represent differences and dependencies, (2) to learn about their consequences, and (3) to transform their knowledge in a way that others can understand.

2.4. Nature of User-Manufacturer Boundary – An Explorative Study at Fidelity Investments

2.4.1. Introduction

In order to investigate the nature of language differences, I analyzed data from an experiment conducted at one of the major financial service companies in U.S. – Fidelity Investments (Fidelity, hereafter). By taking the language-oriented perspective I described in the previous section, I examined the user-manufacturer boundary in the financial services sector. In this section, I will present the result of the study and discuss its findings.

The major finding from this study is that users have heterogeneous language structures and a manufacturer cannot easily cope with diverse user languages. While the language difference may seem to be two-sided, i.e. between a manufacturer and its users, this issue is in fact a multi-faceted one since users are not a coherent language group. Rather, users should be understood as a group of people with diverse language differences.

2.4.2. Research Method and Setting

With the increasing number of transactions happening on the Internet, and shifting focus of Internet sales and customer services, Fidelity conducted a series of usability studies to enhance the usability of the new fidelity.com website – which internally is called the "online 2.0 consumer co-development project." A major part of this study was done by a method called 'card-sorting exercise.' Card-sorting is a technique for organizing different elements in information systems, and has been used in settings such as mainframe operating systems and web site information architectures. In order to come up with the information architecture that caters to user needs, information architect or usability professionals conduct a card-sorting experiment with current or potential users.

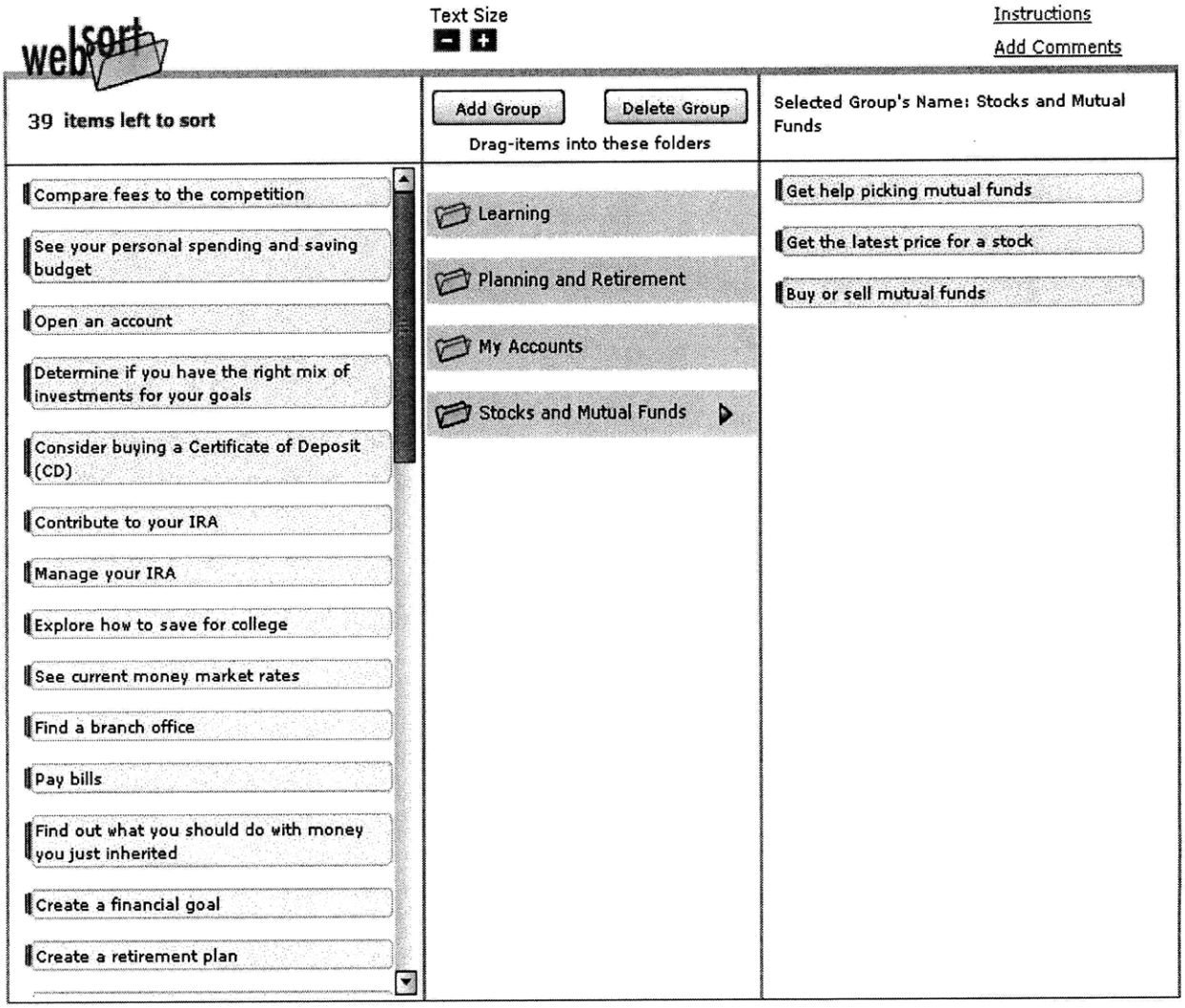
Fidelity screened users based on several criteria. First, they set the age boundaries from 25 to 79. These users were either current Fidelity customers or prospective customers involved in at least two online financial activities – e.g. online banking or visiting Yahoo!Finance – in the past six months.

Then, a series of open and closed card sorting experiments were conducted in order to create the top level navigation structure (internally called high level tabs). There were 46 cards used for 523 participants in the initial open card-sorting experiment (Table 2.1). Card-sorting was done on a web-based card-sorting tool called Websort (http://websort.net). The typical interface of the web-based card-sorting tool is shown below (Figure 2.3).

Table. 2.1. Cards Used in the Open Card-sorting Experiments

Card Number	Contents
1	Buy or sell mutual funds
2	Buy or sell stocks
3	Change your mailing address
4	Chart the past performance of stocks
5	Check status of a money transfer
6	Check your account balances
7	Compare fees to the competition
8	Consider buying a Certificate of Deposit (CD)
9	Contribute to your IRA
10	Create a plan for all of your financial goals
11	Create a retirement plan
12	Determine if you have the right mix of investments for your goals
13	Explore a new investment type - for example, Exchange-Traded Funds (ETFs)
14	Explore how to save for college
15	Figure out when you will have enough money to retire
16	Find a branch office
17	Find out if you are on track for a successful retirement
18	Find out what you should do with money you just inherited
19	Gain more knowledge of options trading
20	Get help picking mutual funds
21	Get the latest price for a stock
22	Investigate analyst's rankings and past performance of mutual funds
23	Investigate types of IRAs
24	Learn about investing
25	Learn how to open a Rollover IRA
26	Manage your IRA
27	Monitor your financial goals, plans, and outcomes
28	Move money between accounts
29	Open an account
30	Pay bills
31	Review your account statements
32	See current money market rates
33	See tax information for your investments
34	See what bonds are available
35	Set up an alert to track the price of a particular security
36	Track the status of a stock order you placed
37	Update beneficiaries for your investment accounts
38	View all your accounts (including accounts from other banks and brokerage companies)
39	View list of stocks you have chosen to track
40	View retirement plan you've created in the past
41	Get advice on managing your debt
42	See your personal spending and saving budget
43	Find ways to lower your taxes
44	Find the best interest rates for your short-term cash savings
45	Buy a life insurance policy that meets your needs
46	Create a financial goal

Figure 2.3. Web-based card-sorting tool



The card-sorting method is relatively simple, but the analysis of the result is rather difficult (Rosenfeld & Morville, 2002). It starts with a bunch of index cards with headings from categories, subcategories, or contents for the system. Then these cards are laid out to the users. They are asked to sort these index cards into groups that make sense to them. Then, in the open card-sorting, the users are asked to label the groups that the cards are assigned to. In the closed card-sorting, labels are given by experimenter. Usually, open card-sorting is used as an exploratory method for examining users' mental models to discover new 'items,' while closed card-sorting is used for as a validation of categories that are created by usability professionals.

The results can visualize users' mental models as well as their linguistic structure. Card-sorting reveals how different users use different terms to indicate the same concepts in the concept cards. With the concepts developed in the semiotic tradition, card-sorting reveals how different users use different signifiers to indicate the same signified (Saussure, 1959). I will discuss this in more detail in the following chapter when I examine a similar issue in the joint product development situation.

While the usual method of analyzing card-sorting data is the hierarchical clustering method, other methods are used in practice such as Multi-dimensional Scaling (MDS). Both methods are used for turning the result of card-sorting data into visible categories that can be utilized for further use. A cluster analysis takes a sample of elements – in this case, assigned labels – and groups them in a way that the variance among the grouped elements is minimized while the variance between groups is maximized (Ketchen & Shook, 1996).

While the original exercises conducted at Fidelity were designed to reveal the information architecture better suited for users, the result from same exercises shed much light on the issues of language differences between a manufacturer and its users.

2.4.3 Findings

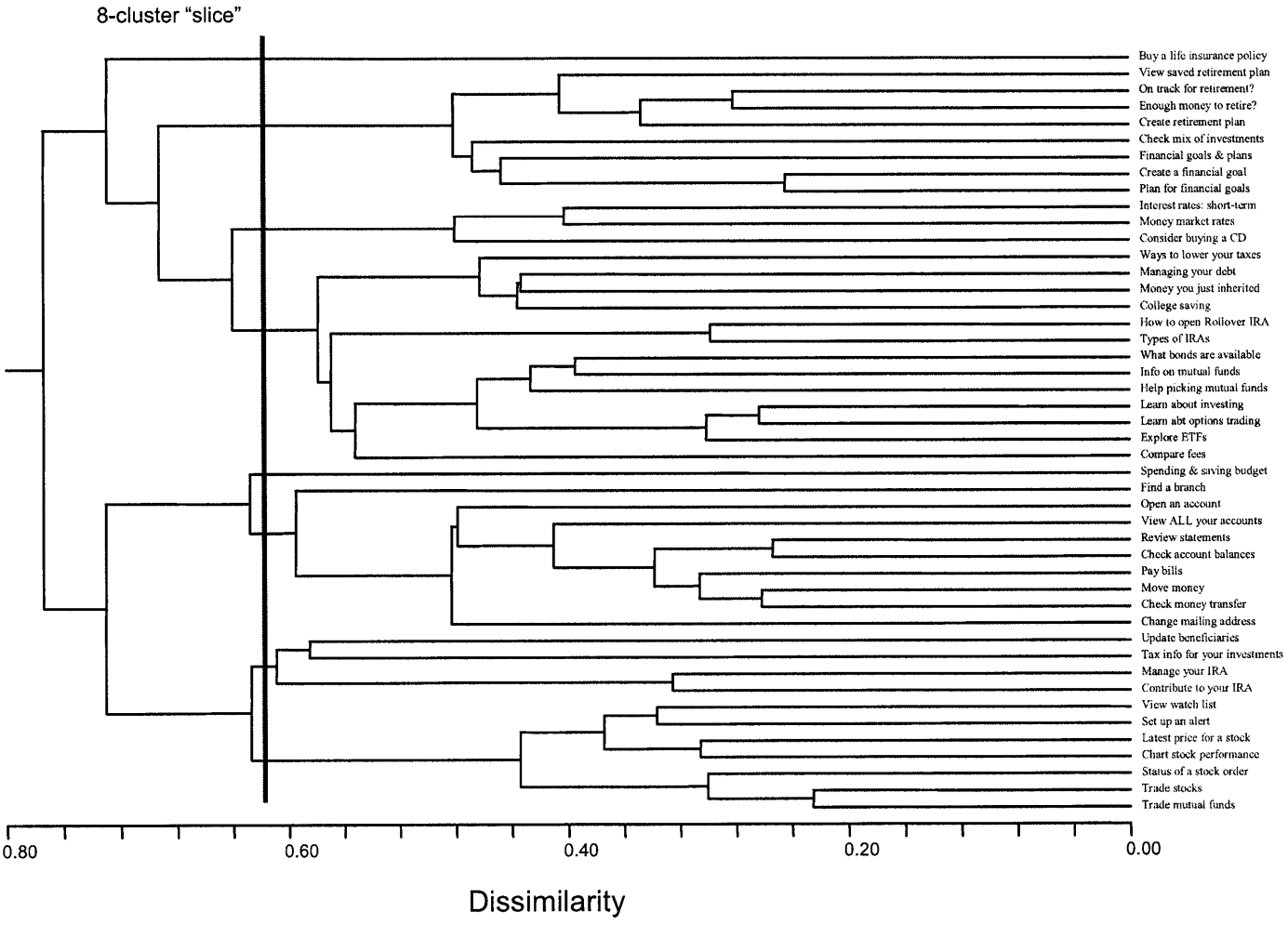
I first present the result of the hierarchical cluster analysis to show how manufacturers, or in this case, service providers, might create a linguistic structure and approach this issue. I then show how users responded to the card-sorting experiments and how diverse user language is. These two different results will help to understand the nature of the inherent language problem between a manufacturer and its users.

The service provider, Fidelity, used a hierarchical cluster analysis inductively to create categories for contents on the web site (Figure 2.4). As we see in Figure 2.4, Fidelity initially decided on eight different clusters to be used for categorizing the responses. This type of decision is arbitrary and there are no clear rules on at which dissimilarity level the clusters should be sliced.

The important finding here is that manufacturers arbitrarily decide how many clusters they will regard as the meaningful number. There are clearly tradeoffs in this decision. With more categories, the manufacturer can accommodate more user diversity, but it also increases complexity and cost in web site management. Therefore, Fidelity keeps searching for the right number and label for the categories they need to create for their information architecture on the web as all rational economic actors would do. In this

process, there is much discussion and political tension since the resulting category can both give an advantage to a part of a firm and give a disadvantage to others.

ıre 2.4. The Result of Hierarchical Cluster Analysis



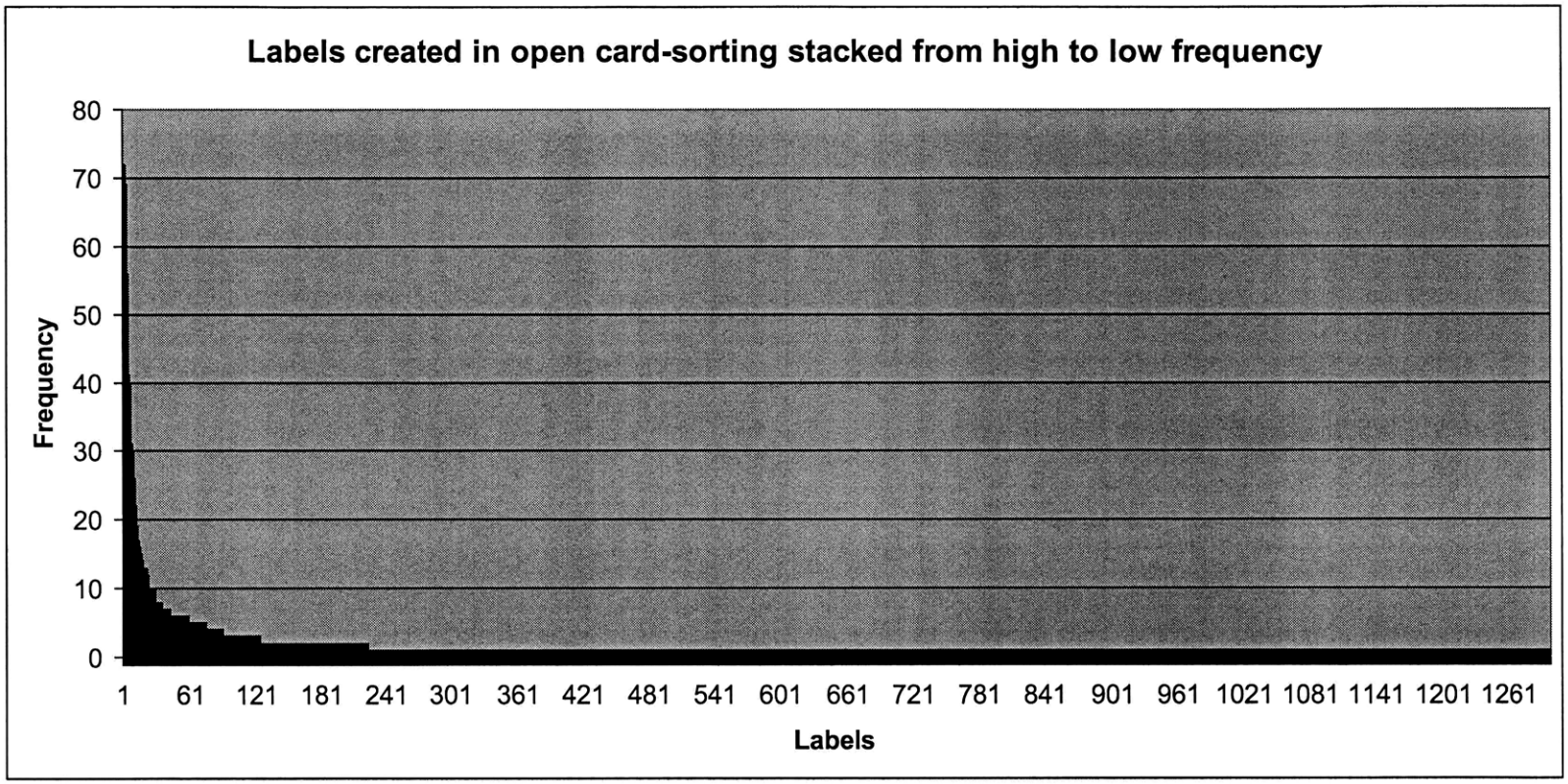
On the other hand, the user side presents a radically different picture. If I aggregate the result of the open card-sorting experiment and look at the distribution of the different labels (Figure 2.5), I observe that there are highly common labels on the left side of the graph and a very long tail on the right side. Out of 1,287 different labels created for 46 concept cards, only 221 labels received two or more votes. This means that there are 1,066 unique labels that are each created by a single individual. Users in this case show their diverse language differences in the way they label different concept cards.

Table 2.2. Descriptive Statistics

Observations
523 users
1287 unique labels

Mean	Std. Dev.	Min	Max
4.97 labels / user	2.26	2	17

Figure 2.5. User-created Labels Sorted by the Frequency (Left – High Frequency, Right – Low Frequency)



2.4.4. Discussion and Conclusion

There are two lessons learned in analyzing the open card-sorting data. First, there are different ways in which the result can be aggregated. For example, the labels 'accounts', 'account maintenance', and 'account information' are all recognized as separate labels. However, one can argue that they are quite similar at a higher level of categorization (accounting) and can be aggregated into one label. But our purpose in this analysis is to examine the diverse nature of language difference on the user side and how it is different from the manufacturer side. As we can see in this example, some users recognize a concept as 'account maintenance', focusing on the maintenance aspect of an individual account, whereas other users labeled the same concept as 'account information' focusing on the informational aspect of the individual account. Since each label represents a slightly different focus on labeling, we leave them as separate labels.

Another lesson is that individuals' have unique perspectives that are different from the service provider. The diversity comes from different perspectives rather than mere different representation or choice of words. For example, users often used the label that is highly individualized such as 'day to day monitoring' or 'things I do occasionally'. These labels are created in the perspectives of individual users rather than the service provider. These individual perspectives are another reason why there is so much diversity on the user side.

The resulting long tail on the right side of Figure 2.5 indicates that no matter how hard the manufacturer tries, it is almost impossible to cope with diverse nature of user

language with a limited number of categories. Even though the manufacturer decides on 10 categories, more than 81% of the users will not be fully satisfied with the presented number of categories.

In the following chapters, I will present empirical evidences and discuss the implication of this language difference. But in this chapter, the difference between the way that the manufacturer decides on the language scheme and the way that the user language scheme is structured illuminates the importance of this language problem.

References

Allen, T. J. 1977a. ***Managing the Flow of Technology: Technology Transfer and the Dissemination of Technological Information within the R&D Organization***. [Cambridge, Mass.: MIT Press].

Allen, T. J. 1977b. ***Managing the Flow of Technology: Technology Transfer and the Dissemination of Technological Information within the R&D Organization***. Cambridge, Mass.: MIT Press.

Ancona, D. G. & Caldwell, D. F. 1992. Bridging the Boundary - External Activity and Performance in Organizational Teams. ***Administrative Science Quarterly***, 37(4): 634-665.

Anderson, P. & Tushman, M. L. 1990. Technological Discontinuities and Dominant Designs - a Cyclical Model of Technological-Change. ***Administrative Science Quarterly***, 35(4): 604-633.

Anderson, P. & Tushman, M. L. 1991. Managing through Cycles of Technological-Change. ***Research-Technology Management***, 34(3): 26-31.

Argote, L., Epple, D., Rao, R., & Murphy, K. 1997. The Acquisition and Depreciation of Knowledge in a Manufacturing Organizations: Turnover and Plant Productivity: Carnegie Mellon University.

Arrow, K. 1962. The Economic Implications of Learning by Doing. ***Review of Economic Studies***, 29: 166-170.

Baldwin, C. Y. & Clark, K. B. 2000. ***Design Rules***. Cambridge, Mass.: MIT Press.

Bowker, G. C. & Star, S. L. 1999. ***Sorting Things Out: Classification and Its Consequences***. Cambridge, Mass.: MIT Press.

Brown, J. S. & Duguid, P. 1991. Organizational Learning and Communities of Practice: Toward a Unified View of Working, Learning, and Innovation. ***Organization Science***, 2(1): 40-57.

Burns, T. & Stalker, G. M. 1961. ***The Management of Innovation***. [London]: Tavistock Publications.

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

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

Coase, R. 1937. The Nature of the Firm. ***Economica***, 4: 386-405.

Cyert, R. M. & March, J. G. 1992. ***A Behavioral Theory of the Firm*** (2nd ed.). Cambridge, Mass., USA: Blackwell Business.

Daft, R. & Macintosh, N. 1981. A Tentative Exploration into the Amount and Equivocality of Information Processing in Organizational Work Units. ***Administrative Science Quarterly***, 26: 207-224.

Daft, R. & Weick, K. 1984. Toward a Model of Organizations as Interpretation Systems. ***Academy Of Management Review***, 9(2): 284-295.

Davenport, T. H. & Prusak, L. 1998. ***Working Knowledge: How Organizations Manage What They Know***. Boston, Mass: Harvard Business School Press.

Dewey, J. 1938. ***Logic, the Theory of Inquiry***. New York: H. Holt and company.

Dougherty, D. 1992. Interpretive Barriers to Successful Product Innovation in Large Firms. ***Organization Science***, 3(2): 179-202.

Duncan, R. 1972. Characteritics of Organizational Environments. ***Administrative Science Quarterly***, 19: 313-327.

Eppinger, S. D., Whitney, D. E., Smith, R. P., & Gebala, D. A. 1994. A Model-Based Method for Organizing Tasks in Product Development. ***Research in Engineering Design-Theory Applications and Concurrent Engineering***, 6(1): 1-13.

Frischmuth, D. & Allen, T. 1969. A Model for the Description and Evaluation of Technical Problem Solving. ***IEEE Transactions on Engineering Management***, EM-16(2): 58-64.

Galbraith, J. 1977. ***Organizational Design***. Mass.: Addison-Wiley.

Galbraith, J. R. 1973. ***Designing Complex Organizations***. Reading, Mass.: Addison-Wesley Pub. Co.

Grant, R. M. 1996. Toward a Knowledge-Based Theory of the Firm. ***Strategic Management Journal***, 17: 109-122.

Hage, J. & Aiken, M. 1969. Routine Technology, Social Structure, and Organizational Goals. ***Administrative Science Quarterly***, 14: 366-379.

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

Huber, G. P., Oconnell, M. J., & Cummings, L. L. 1975. Perceived Environmental Uncertainty - Effects of Information and Structure. ***Academy of Management Journal***, 18(4): 725-740.

James, W. 1963. ***Pragmatism, and Other Essays***. New York: Washington Square Press.

Jurkovich, R. 1974. A Core Typology of Organizational Environments. ***Administrative Science Quarterly***, 19(3): 380-394.

Katz, D. & Kahn, R. L. 1966. ***The Social Psychology of Organizations***. New York: Wiley.

Ketchen, D. J. & Shook, C. L. 1996. The Application of Cluster Analysis in Strategic Management Research: An Analysis and Critique. ***Strategic Management Journal***, 17(6): 441-458.

Klein, B., Crawford, R. G., & Alchian, A. A. 1978. Vertical Integration, Appropriable Rents, and the Competitive Contracting Process. ***Journal of Law & Economics***, 21(2): 297-326.

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

Lave, J. & Wenger, E. 1991. ***Situated Learning: Legitimate Peripheral Participation***. Cambridge [England]; New York: Cambridge University Press.

Lawrence, P. R. & Lorsch, J. W. 1967. ***Organization and Environment; Managing Differentiation and Integration***. Boston: Division of Research, Graduate School of Business Administration, Harvard University.

Lawrence, P. R. & Lorsch, J. W. 1969a. ***Organization and Environment; Managing Differentiation and Integration***. Homewood, Ill.: R. D. Irwin.

Lawrence, P. R. & Lorsch, J. W. 1969b. ***Developing Organizations: Diagnosis and Action***. Reading, Mass.: Addison-Wesley Pub. Co.

Levitt, B. & March, J. G. 1988. Organizational Learning. ***Annual Review of Sociology***, 14: 319-340.

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

Marples, D. L. 1961. The Decisions of Engineering Design. ***IEEE Transactions on Engineering Management***, 2: 55-71.

Murmann, J. P. & Frenken, K. 2006. Toward a Systematic Framework for Research on Dominant Designs, Technological Innovations, and Industrial Change. ***Research Policy***, 35(7): 925-952.

Nelson, R. R. & Winter, S. G. 1982. ***An Evolutionary Theory of Economic Change***. Cambridge, Mass.: Belknap Press of Harvard University Press.

Orr, J. E. 1996. ***Talking About Machines: An Ethnography of a Modern Job***. Ithaca, N.Y.: ILR Press.

Perrow, C. 1967. A Framework for the Comparative Analysis of Organizations. ***American Sociological Review***, 32: 194-208.

Polanyi, M. 1966. ***The Tacit Dimension***. Garden City, New York: Doubleday & Company, Inc.

Rosenfeld, L. & Morville, P. 2002. ***Information Architecture for the World Wide Web*** (2nd ed.). Cambridge, Mass.: O'Reilly.

Sanchez, R. & Mahoney, J. T. 1996. Modularity, Flexibility, and Knowledge Management in Product and Organization Design. ***Strategic Management Journal***, 17: 63-76.

Saussure, F. d. 1959. ***Course in General Linguistics***. New York: Philosophical Library.

Shannon, C. E. & Weaver, W. 1949. ***The Mathematical Theory of Communication***. Urbana: University of Illinois Press.

Simon, H. A. 1973. The Structure of Ill Structured Problems. ***Artificial Intelligence***, 4: 181-201.

Teece, D. J., Pisano, G., & Shuen, A. 1997. Dynamic Capabilities and Strategic Management. ***Strategic Management Journal***, 18(7): 509-533.

Thomke, S. & von Hippel, E. 2002. Customers as Innovators - a New Way to Create Value. ***Harvard Business Review***, 80(4): 74-81.

Thompson, J. D. 1967. ***Organizations in Action; Social Science Bases of Administrative Theory***. New York: McGraw-Hill.

Tushman, M. L. 1977. Special Boundary Roles in Innovation Process. ***Administrative Science Quarterly***, 22(4): 587-605.

Tushman, M. L. 1978. Technical Communication in R and D Laboratories - Impact of Project Work Characteristics. ***Academy of Management Journal***, 21(4): 624-645.

Tushman, M. L. & Nadler, D. A. 1978. Information Processing as an Integrating Concept in Organization Design. ***Academy of Management Review***, 3(3): 613-624.

Tushman, M. L. & Anderson, P. 1986. Technological Discontinuities and Organizational Environments. ***Administrative Science Quarterly***, 31(3): 439-465.

Tyre, M. J. & von Hippel, E. 1997. The Situated Nature of Adaptive Learning in Organizations. ***Organization Science***, 8(1): 71-83.

Ulrich, K. T. & Eppinger, S. D. 2004. ***Product Design and Development*** (3rd ed.). Boston: McGraw-Hill/Irwin.

Van de Ven, A., Delbecq, A., & Koeig, R. 1976. Determinants of Coordination Modes within Organizations. ***American Sociological Review***, 41: 322-338.

Virany, B., Tushman, M. L., & Romanelli, E. 1992. Executive Succession and Organization Outcomes in Turbulent Environments - an Organization Learning Approach. ***Organization Science***, 3(1): 72-91.

von Hippel, E. 1990. Task Partitioning - an Innovation Process Variable. ***Research Policy***, 19(5): 407-418.

von Hippel, E. & Tyre, M. J. 1995. How Learning by Doing Is Done - Problem Identification in Novel Process Equipment. ***Research Policy***, 24(1): 1-12.

Weick, K. E. 1979. ***The Social Psychology of Organizing*** (2d ed.). Reading, Mass.: Addison-Wesley Pub. Co.

Wernerfelt, B. 1984. A Resource-Based View of the Firm. ***Strategic Management Journal***, 5(2): 171-180.

Wernerfelt, B. 1995. The Resource-Based View of the Firm - 10 Years After. ***Strategic Management Journal***, 16(3): 171-174.

Williamson, O. E. 1975. ***Markets and Hierarchies, Analysis and Antitrust Implications: A Study in the Economics of Internal Organization***. New York: Free Press.

Williamson, O. E. 1981. The Economics of Organization - the Transaction Cost Approach. ***American Journal of Sociology***, 87(3): 548-577.

Zaheer, A. & Venkatraman, N. 1994. Determinants of Electronic Integration in the Insurance Industry - an Empirical-Test. ***Management Science***, 40(5): 549-566.

CHAPTER 3: MANIFESTATION OF LANGUAGE TRANSFER PROBLEM DURING THE NEW PRODUCT DEVELOPMENT PROCESS

3.1. Introduction

Many firms explore areas outside their boundaries to reap the benefits of networking and the opportunity to explore diverse ideas, experiences, and perspectives not available within their own firms (Owen-Smith & Powell, 2004; Powell, Koput, & SmithDoerr, 1996). Some firms shift their boundaries towards other companies in order to reduce the cost of transaction (Pisano, 1990; Williamson, 1991), while others look towards the user side due to the fundamental difficulty of shifting sticky information (von Hippel, 1994).

When the locus of innovation is shifted outside of a firm, society will benefit from this effect by sharing the innovative outcomes (DiBona, Ockman, & Stone, 1999). Companies may also benefit from the innovative outcomes by incorporating them within their products and also developing new innovative products "on top of" them. For example, an industrial design company in the U.S., IDEO, uses its unique position in its network to obtain diverse knowledge generated from outside of the firm, and uses its internal mechanism to synthesize and generate a new kind of innovation (Hargadon & Sutton, 1997).

Traditional innovation and organizational studies focus on examining the collaborative efforts in the new product development process inside the firm and identifying the main drivers of effectiveness (Cusumano & Nobeoka, 1998; Katz & Allen, 1985). However, entities inside a firm also seek innovation by sometimes directly collaborating with entities outside the firm. Yet research on this micro process of collaboration between a firm and outside partners (clients or suppliers) has been lacking sufficient attention (Brown & Eisenhardt, 1995).

Understanding how users utilize products has become an increasingly important focus for studies (and firms and industries) aimed at identifying ways to deliver successful products to the market (Christensen, Cook, & Hall, 2005). A firm's internal research and development is an important pre-condition for effective collaboration with outsiders (Cohen & Levinthal, 1990). But a firm's internal capability *per se* does not guarantee the smooth flow of knowledge inwards. Without understanding the nature of boundaries that distinguish those inside and outside the firm and the nature of collaborative problem-solving in this area, it is difficult to manage the micro process of collaboration. Managing these boundaries is critical to obtaining successful outcomes when reaching outside a firm for a new source of innovation.

At the center of collaborative development for new products lies the issue of communication gaps created by language problems. When two engineers are engaged in a new product development process, they will naturally speak different languages. Prior organizational study identifies the sources of language gap that generate different natures of knowledge boundary (Carlile, 2004; Dougherty, 1992), and ways in which organizational members mitigate this language gap (Bechky, 2003; Pawlowski & Robey, 2004). These literatures are elaborated in Chapter 2.

This chapter extends what we know about boundaries from the existing theories and empirical findings, and focuses on a specific type of collaborative product design process *between a manufacturer and its users*. I explore the collaborative user-manufacturer problem-solving process in the product development stage. By using the Grounded Theory Building method with multiple data sources, I develop a process model of how

user-manufacturer problem-solving language differences can negatively affect the collaboration.

In this chapter, I use the basic notion of scientific and engineering problem-solving to explain how language difference can be mitigated by local trial-and-error learning. What is important in this process is that the information that has to be transferred is limited and bounded by the interdependency that exists between two parties involved in joint problem-solving. Investigation into the communication between the seemingly disparate groups – a manufacturer and its users – reveals that the language boundary can be mitigated by local coordination based on the technical interdependencies between user requirement and technological implementation. Using the concept of 'trading zone' (Galison, 1997), localness of communication and joint problem-solving are emphasized in the collaboration between users and a manufacturer.

In the actual problem-solving situation, the technical interdependency between user requirement and the final product plays an important role in generating the local trading zone. This provides a venue for two disparate groups of people – in the current field study setting, the mechanical engineering-oriented manufacturer and the electrical engineering-oriented users of the manufacturer – to engage in joint problem-solving. This paper shifts our attention towards the actual process of mitigating language difference through local coordination at the user-manufacturer boundaries.

3.2. Literature Review and Conceptualization

3.2.1. User-Manufacturer Problem-Solving in the New Product Development Process

The communication and collaboration between users and manufacturers have often been recognized in the extant literature as rather unidirectional. Manufacturers gather user needs and develop products based on input from users (Clark & Wheelwright, 1993; Ulrich & Eppinger, 2004). After gathering user input, firms use their own mechanisms such as the "development funnel" or "stage-gate system" to process the generated ideas (Clark & Wheelwright, 1993; Cooper, 1990). In this process, user needs are conceptualized as crystallized elements that, in turn, become the input for the production system. But in fact, the main difficulty of product innovation lies in the process of extracting user needs.

During the new product development process, identifying user needs is one of the most critical tasks since it determines the features and functions of products and services. Many different approaches have been researched and used in practice; for example, interviews (Griffin & Hauser, 1993) and the lead user method (von Hippel, Thomke, & Sonnack, 1999). The former approach is based on an underlying assumption that users know their needs *ex ante*, which can be articulated. The latter method collects information about solutions developed by lead users themselves in response to their own needs. Data on needs apart from prototype solutions is not collected in the lead user approach. It also focuses on users with leading-edge needs.

In contrast, the ethnographic approach acknowledges that users can be so accustomed to the current situation that they fail to provide any meaningful information for manufacturers via communication (Leonard & Rayport, 1997). In response to this situation, the ethnographic approach attempts to extract meaningful user needs from observing the interaction between users and their environment.

While the collected data provides much information in great detail about the use of a technology, this method can do so only in a very specific and limited use environment since the targeted users represent only a small portion of the population. Alexander (1964) stated that the design of an artifact is that of a form to fit with the context. This design specificity is often what designers focus on compromising the generality of design. It is very difficult to devise a method or tool that is suited for all the different environments or problems. Moreover, as users often learn from their use of a product (Rosenberg, 1982), evolving user needs can rarely be captured using this type of an approach as it involves a large cost and effort. Interpreting and making sense of what users identify as the major requirement is not an easy task, and this part of the new product development is often called the "fuzzy front end" due to its complex and indeterminate nature (Moenaert, Demeyer, Souder, & Deschoolmeester, 1995).

The fuzziness stems from the fact that new product development is a trial-and-error process (Allen, 1966; Brown & Eisenhardt, 1995; Clark & Fujimoto, 1991; Frischmuth & Allen, 1969; Thomke, 1998). Research and development departments as well as manufacturing departments engage in such problem-solving activities on a daily basis. As we learn more about the product or the process to develop a product or service, we get a better idea of the working mechanisms (Pisano, 1996; Simon, 1973). This enhanced

learning further enlightens the development process, thus increasing the depth of knowledge for those working toward a solution.

Another important characteristic of this problem-solving process in product development is that it is collaborative and interactive. This process requires not only constant and clear communication among the members of the R&D laboratories or new product development teams, but also communication with outside members (Ancona & Caldwell, 1992; Tushman, 1977, 1978). Cross-functional new product development teams and communication with outsiders bring fresh ideas and perspectives that are critical in developing new products. Collaborative and interactive problem-solving is also identified as an important mechanism that helps integrate product and process innovation (Clark & Fujimoto, 1991; Pisano, 1996).

However, many scholars assert that there are fundamental differences in how a group of people recognize and interpret things. For instance, there are variations in cognitive schemes and routines stemming from people's perspectives, cultures, and disciplines. Such differences can hinder the continuous flow of diverse ideas and opinions (Dougherty, 1990). Similarly, Leonard-Barton (1995) identified three sources of individual differences in problem-solving: specialization, cognitive style, and preferences for specific tools and methods. Combined with other organizational mechanisms that make an organization very rigid in terms of corresponding to changes (Leonard-Barton, 1992), these sources of separation and isolation make organizations inflexible. These differences stem from 1) the fundamental differences in how people think, and 2) the habits of thoughts accumulated by prior experience. These two sources are not entirely separable since the problematic search behavior continually updates the current cognitive

scheme and may affect future search behavior as well (Cyert & March, 1963; Newell & Simon, 1972). Whether cognitive scheme differences develop from a prior experience or a tendency to do a local search, the disparities could have a detriment effect on collaborative problem-solving efforts. If two parties involved in a joint problem-solving process have a different cognitive scheme and knowledge structure, it will be challenging for each of them to understand the meaning that the other is trying to convey. Indeed, the collaborative problem-solving process seems to work as a double-edged sword; it can help parties utilize their diverse experiences and enhance the problem-solving capacity, but at the same time, it can cause miscommunication and misunderstanding.

In the collaborative product development process between users and manufacturers, this problematic situation is very prominent. The strong boundary between the two parties is not only physical or geographical, but it is also cognitive and emotional. While manufacturers develop an understanding about their product and process through learning-by-doing, users lack this experience. On the other hand, manufacturers are bound by their search capabilities; therefore, they lack an understanding about users' diverse knowledge and backgrounds (Cyert & March, 1992; March & Simon, 1958). The strong cognitive boundary between users and manufacturers should be examined thoroughly to identify the impact of the boundary on the performance of the joint problem-solving process.

Before I move on to examine the joint problem-solving process between users and manufacturers, I must establish a very key concept: *problem-solving language*. In the following section, I define the concept of problem-solving language and discuss its role in the product development process. A stream of research on knowledge-based views of a

firm has used the term *knowledge* to explain the content of learning and the process of sharing the results of learning (Kogut & Zander, 1992; Nonaka & Takeuchi, 1995). While this conceptualization helps to characterize and understand how organizations and their employees create, store, and transfer what they know, it is a very broad concept and does not fully reflect the essence of the joint problem-solving process, which involves the exchange of existing problem-solving tools and methods. Moreover, it has been found that both the concept and how it is represented is important in transferring knowledge. By fully explaining the concept of problem-solving language in the following section, I will have a theoretical lens to examine the joint user-manufacturer problem-solving process.

3.2.2. Problem-Solving Language

One of the primary mechanisms that reduced cognitive scheme differences in collaborative problem-solving was identified by Clark and Fujimoto (1991). They referred to computer-aided design (CAD) and computer-aided engineering (CAE) as "a new 'language' that will allow different functional groups with their own 'dialects' to develop shared understanding" (p. 333). Examples include digitized engineering drawings, high-fidelity simulation software, and realistic 3-dimensional (3D) styling models. Other studies have followed this research tradition and have examined the role of computer-aided tools both in product development (Thomke, 1998) and process development (Pisano, 1996). While Clark and Fujimoto (1991) provided a useful framework for understanding the role of computer-aided tools in product and process

development, they did not identify specific reasons as to why they chose to use "language" for the concept.

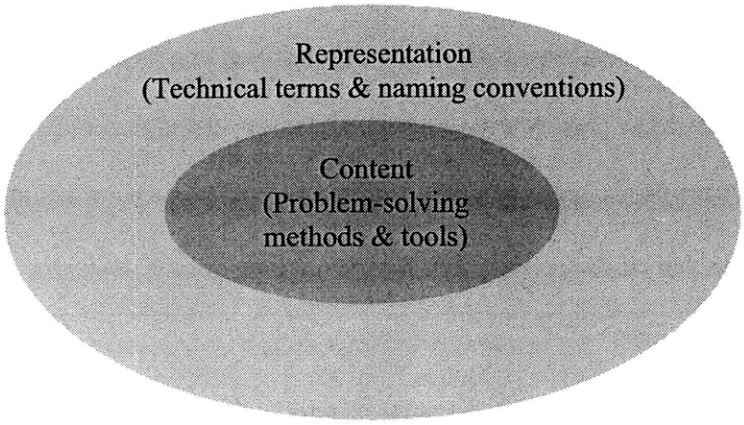
Clark and Fujimoto's (1991) use of the word "language" to describe CAD and CAE can be hinted in Bucciarelli's work (2002). Bucciarelli established the notion of language in the engineering problem-solving context. In his conception of 'object world,' he focused on the world of individual engineers applying one's expertise to particular tasks relating to one's own discipline. Different participants with different competences, skills, responsibilities, and interests develop different ways of viewing their worlds: hence they speak different 'object world languages.' In solving their own set of problems, structural engineers speak of stress, strain, displacement, stiffness, and load path, while electronics engineers speak of power, voltages and currents, analogue and digital, resistance and capacitance (p.222-223). In the engineering world, language is in part the result of invested problem-solving and in part the result of creating something that does not exist at the point of designing. Therefore, everything that refers to some feature of the product or process is a linguistic element in the object world: charts, acronyms, sketches, diagrams, models, mock-ups, existing product line, and specifications on the contractual document (p.228).

Building on this conceptualization, problem-solving language is defined in this paper as *the identified and well-proven*[1] *tools and methods used for solving engineering problems*. In this study, problem-solving language is a more general concept that

[1] "Well-proven" means that the problem-solving language is shared and acknowledged by the people who are involved in the problem-solving process. Even though traditional cognitive science literature views problem-solving as a very individualistic process (Anderson, 2000), we refer to both the individual and collaborative problem-solving process when we discuss problem-solving in this paper.

encompasses both the tools and methods as the *content*, and the technical terms and naming conventions as the *representation of the content* (Figure. 3.1).

Figure 3.1. Problem-solving Language as Both Content and Representation



The structure in which the meanings and their surrounding forms are related can be shown with the concepts developed in semiotic tradition in linguistics. Saussure (1959) distinguished the language system into two parts: the *signified* and *signifier*. The 'signified' is a concept or meaning which is expressed through the form. This is the 'signifier', which is the external part of the language. The relationship between signified and signifier is arbitrary, but the selection is sometimes regulated by the consensus of linguistic community members. People in a manufacturing organization develop and learn a particular subjective viewpoint and speak their own language. Users do the same thing only in a different setting – their own linguistic community. While the signified may be the same across the user-manufacturer boundary, the signifier can be quite different given the context in which the economic actors are embedded in. To illustrate

this point, let us assume a simple example. In the English language, a noun 'dog' is used for the concept, "a highly variable domestic mammal closely related to the gray wolf." But in Korean language, the same concept is carried by the word, '*gae*'. While the signified in this case is the same, the signifier is different in two languages, making seamless communication difficult.

On the other hand, a particular expression of knowledge (signifier) can potentially signify multiple contents (Barthes, 1967). In the example given by Bechky (2003), the same signifier 'doctor' can signify a surgeon in a hospital waiting room giving the news of a successful triple bypass, an image of a doctor on television, or the emotive connotation of care. Given the context in which the word 'doctor' is given, different images of 'doctor' are invoked.

Here, I need to clarify several issues related to the definition of *problem-solving language*. First, in order to explore inter-group communication at the user-manufacturer boundary, it is very important to establish the relationship between languages as a representation and as a content that the representation actually represents. When conceptualizing the tools and methods—*the content aspect of the problem-solving language*—the problem-solving language concept is the only concept of concern; hence, there is no real need to discuss the representation aspect. But in the discussion of the collaborative aspect of the problem-solving process, the *problem-solving language as a representation of a concept* becomes crucial. When people try to transmit what they know as well-proven methods or tools, they need to express this using the technical terms and unique naming conventions created or used by those engaged in the general problem-solving process (Arrow, 1969).

Allen (1977) identified communication as the key mechanism in knowledge transfer in R&D organizations. He established the concept of gatekeepers and identifies them as the bridges between the inside and outside boundaries of organizations. Many scholars followed this tradition of research and found that the effectiveness of this bridging mechanism via human agents depended on the nature of the project such as task interdependence, task environment, and task orientation (Allen, Tushman, & Lee, 1979; Tushman, 1977; Tushman & Katz, 1980). The results showed that the role of the gatekeeper, in other words, the role of the human agent as a translator, was less significant in an unstable environment. Uncertainty in a group's task and the environment requires more information to be processed; therefore more people are required to directly interact with the entities outside the boundary in research projects compared to development projects (Allen et al., 1979; Tushman & Katz, 1980). Similarly, the boundary between a manufacturer and its users is very strong in that the information is sticky and not easily transferable (von Hippel, 1994). As we discussed earlier, the identification of a need is an emergent process that involves high uncertainty. In this case, a firm must have an adequate number of gatekeepers to address both environmental uncertainty and informational stickiness. This, in turn, means that the direct communication between entities on the users' and manufacturers' side involves great effort and clear communication to make sense of what the other side means. In order to explain this communicational aspect of the user-manufacturer boundary, I need to have a theoretical lens that encompasses both the content of the problem-solving method, and also the technical terms and naming conventions that represent the content.

Second, language as both the concept and the representation is crucial to explain the intra-group communication that leads to a unique language group, which in turn, has an effect on the inter-group communication. When people invent a novel way to approach a problem, they experiment with it and validate it through simulations (Thomke, 1998) or in actual practice (Thomke, 2003). When the approach is successfully validated and repetitively used in practice, this identified and well-proven method becomes embedded as an organization's problem-solving language. This intra-group process is very similar to what Japanese companies follow in their practice to integrate individual knowledge and transform it into organizational knowledge (Nonaka & Takeuchi, 1995). In this 'socialization' process, people make implicit knowledge explicit, for example, by documentation and verbalization. While the people who are involved in this socialization process within a certain boundary of an organization become familiar with the connection between the concept and the representation, people outside the boundary feel it is very difficult to connect the verbalized (or documented) technical terms and the actual methods they represent. Therefore, the natural process of forming a unique language group can become problematic when the language has to be shared with people outside that group. People generally know more than they can easily articulate (Polanyi, 1966), and this tacit nature of some knowledge can impede communication when it crosses a certain boundary. The sticky nature of information also sometimes intensifies this boundary effect (von Hippel, 1994). But even when the knowledge is well articulated as in the case of problem-solving methods and tools, communicating it becomes problematic due to the very relationship between the content and the representation. While we can easily understand a simple problem-solving method developed by a manufacturer, it may

be difficult to understand it, not because the problem-solving method is inherently difficult, but because the representation of the problem-solving method is too unfamiliar to us.

Finally, the pool of tools and methods that has been the primary focus in studies about innovation has to be expanded. Existing studies focus on computer-aided methods and tools. But during the problem-solving process, engineers[2] find many interesting solutions to problems, and certain problem-solving methods and tools persist over time unless a new and improved solution prevails (Landes, 2000). Therefore, the problem-solving language concept should not be limited to computer-aided software, but should be extended into many other process technologies and equipment that are byproducts of the problem-solving process.

The concept of problem-solving language is well supported by cognitive science literature. Designing a new product is a process of transforming an ill-structured problem into a well-structured problem (Anzai & Simon, 1979; Simon, 1973; Simon *et al.*, 1987). During this design process, a well-structured part of the grand problem is repetitively used to solve the problem. Since the ultimate goal of problem-solving is to find the route to the ultimate solution (Newell & Simon, 1972), finding and storing the well-structured area of the problem is very important in improving future problem-solving. This well-structured area of the problem is not only limited to individuals, but often identified and

[2] Scientists also find solutions to problems by theorizing and empirically proving the validity of the theory. But engineers usually find more hands-on solutions that solve a certain problem and these solutions evolve over time. For example, numerous solutions to the clock escapement mechanisms were invented over a long period of time (Landes, 2000). Allen (1977) discussed the difference between the scientists and the engineers in many aspects. While this topic is beyond the scope of this paper, it is interesting to see how the problem-solving process is prevalent in all dimensions of technological innovation.

shared among the many individuals who participate in the problem-solving process as explained above.

In a collaborative environment, the problem-solving language can be used as a common language that facilitates cross-functional collaboration (Carlile, 2004; Clark & Fujimoto, 1991). But at the same time, differences in problem-solving languages can lead to problems due to language-related misunderstandings. In the next section, I discuss the differences in problem-solving language addressed mainly in cognitive science literature.

3.2.3. Cognitive Science Literature on Differences in Problem-Solving Language

Cognitive science scholars have long been interested in analyzing the basic differences between how people think and perceive. People tend to use meaning-based knowledge representations that involve significant abstraction from the experiences that originally delivered that knowledge. For example, when students go to class to learn a subject, many will often forget what the teacher wore, but will have some memory of what the teacher taught (Mandler & Ritchey, 1977). The abstraction in this case is done by eliminating the perceptual details and keeping a narrow focus on the important relationship among the specific elements. Other mechanisms of abstraction involve making general categorizations based on prior experience. Research on the categorization process has focused on both how these categories are formed and how people use them to interpret new experiences (Quillian, 1966). Collins and Quillian empirically demonstrated that these categories form a semantic network by measuring the difference in the retrieval time of the structured knowledge (1969). This basic structure of our

conceptual knowledge is not free from the experiential effect. The retrieval time of the knowledge is strongly related to the frequencies of which facts are experienced (Conrad, 1972).

Although the semantic network concept explains how our cognitive scheme might be constructed differently by the frequency of an experience, it does not capture the approximate nature of our knowledge and the process by which we store information about the metadata. Researchers in cognitive science have proposed a particular way for representing such metadata: a schema[3] (Rumelhart & Ortony, 1976). Schemas are abstractions from specific instances that can be used to make inferences (Anderson, 2000). For instance, when we think about a house, we can use the schematic definition and infer that the house has windows, walls, and so on. Schemas represent concepts in terms of supersets, parts, and other attributes and values.

The way we construct our knowledge such as the semantic network and schema affects how we frame and solve problems. This fundamental difference in how people think not only makes communication between two heterogeneous parties difficult, but also affects the joint problem-solving process. This distinction in knowledge structure is often manifested in language differences. For example, the difficulty in a cross-functional product development team may arise from not only cognitive differences, but also from language differences caused by cognitive differences (Dougherty, 1990).

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[3] Marshall (1995) defined a schema by aggregating the extant literature as the following :

A schema is a vehicle of memory, allowing organization of an individual's similar experiences in such a way that the individual ...

- *can easily recognize additional experiences that are also similar, discriminating between these and the ones that are dissimilar;*
- *can access a generic framework that contains the essential elements of all of these similar experiences, including verbal and nonverbal components;*
- *can draw inferences, make estimates, create goals, and develop plans using the framework; and*
- *can utilize skills, procedures, or rules as needed when faced with a problem for which this particular framework is relevant.*(p.39)

However, in the collaborative problem-solving process, cognitive differences are manifested explicitly in various ways. In many cases, cognitive differences between users and manufacturers stem from the difference in their level of expertise and how they dissect problems. Experts and novices have very different modes of framing a problem and solving it (Larkin, Mcdermott, Simon, & Simon, 1980). Problem chunking has been identified as the basic mechanism in the problem-solving process (Newell & Simon, 1972; Simon, 1974). During the learning-by-doing process, people use the chunking mechanism to solve the most obvious part of a grand problem (Anzai & Simon, 1979). Anzai and Simon showed that people follow a sequence of problem-solving processes without pausing or referencing sub-goals. These chunks play an important role in establishing a problem-solving strategy since they minimize the effort spent to make decisions about smaller parts of a problem. Problem chunking not only saves time, but it also lessens the required cognitive burden during the complex problem-solving process. The design process itself is an ill-structured problem (Simon, 1973). In design tasks, it is very difficult to find the definite structure of the design problem early on in the process. Rather, a certain structure of the design problem emerges as a designer finds well-structured sub-problems and keeps updating this well-understood part. Therefore, if well-structured sub-problems cannot be easily identified, it can be very challenging to proceed with the design task since the overall structure of the problem remains ill-defined.

Manufacturers go through this process when doing R&D to create the initial product design; hence, they hold many well-defined sub-problems and solutions in the form of tools and methods. Therefore, manufacturers have expertise in some areas of the grand problem. This holds true for users as well, who develop their own distinct set of

knowledge about problems and often develop solutions by themselves as well (von Hippel, 1994). Users are spread out in many areas of distinct expertise, which may contribute to the final solution. These differences between manufacturers and users sometimes lead to differences in the problem-solving language, especially if one party has devised its own methods and tools while working on the sub-problems.

While the differences in problem chunking can be the antecedent of problem-solving language differences, the effects of problem-solving language differences can be manifested in various ways. Functional fixedness is one example (Duncker, 1945). In a classical experiment, subjects are presented with a situation that requires them to use a familiar object to perform a novel function in order to solve a particular task (Adamson, 1952). In this experiment, people seem unable to grasp new ways of using objects (which could lead to innovative solutions) because their minds are blocked or fixated on the established uses or properties of an object. This is due to the failure to appropriately represent the problem.

Similar to the way that a representation of a problem molds how people develop a frame for and a solution to a problem, how people select a certain problem-solving operator also affects the route to the final solution. In most disciplines, people tend to use traditional, proven solutions for new situations or problems even when it may be clear that an old solution no longer works (Luchins, 1942). This is known as a "set effect" or "Einstellung effect." In general, set effects occur when some knowledge structures are readily available at the expense of other knowledge structure. If the available knowledge is what subjects need to solve a problem, their problem-solving ability will be facilitated. If not, problem-solving can be inhibited by the lack of key information (Anderson, 2000).

For example, users can be so accustomed to the way they solve problems that they sometimes mentally resist using the manufacturer's problem-solving language.

In addition to the fact that users and manufacturers are distant and usually not involved in a joint problem-solving process, many diverse mechanisms such as problem chunking, functional fixedness, and set effect can be problematic. As mentioned before, joint problem-solving between users and manufacturers is both an individual and collaborative mechanism; therefore, we need to consider both concepts to reconcile and explain what happens in this area. Since tools and methods are sometimes provided by manufacturers, users often experience a functional fixedness problem or a set effect during the problem-solving process. Even though the difficulty in problem-solving lies in the individual process, the source of the problem is often due to the fact that users and manufacturers exchange their problem-solving language to solve a problem. This problem becomes more evident when they develop a new product together in joint product development projects.

While the cognitive science literature informs us about the antecedents and effects of problem-solving language differences, we need a strong empirical ground to see the effects of this difference in a collaborative problem-solving process. In this setting, users and manufacturers engage in the collaborative problem-solving process through direct communication to come up with a new product design.

3.2.4. Problem-Solving Language Difference and Its Consequences in the Collaborative Problem-Solving Process

The goal of the present study is to enrich our understanding of the collaborative problem-solving process between users and manufacturers. Their problem-solving language differences may hinder both parties from understanding each other and from engaging in the joint problem-solving process. But how will this language difference actually manifest itself in the product development process? My investigation of joint problem-solving in the new product development process is aimed to answer this question by examining and identifying the details of this process as it unfolds.

In order to examine this research question, I conducted a field study using multiple methods to build a plausible theory behind the joint problem-solving that encompasses the strong boundary between users and manufacturers. The field study method in this paper provides the means to intimately connect to the empirical reality, which permits the development of a testable, relevant, and valid theory (Glaser & Strauss, 1967). Grounded Theory Building is especially compatible with management research because it enables researchers to capture the complexity of organizational situations and processes, and because it allows the investigation of new areas, such as high-technology organizations and other new topics (Locke, 2001). The process model developed in this process indicates that the boundary object can be an important mechanism that can increase the effectiveness of the communication between users and a manufacturer. Additional data was gathered to further explore this issue.

The various methods used in this study enabled me to triangulate the findings from multiple reference points, which helps to improve the accuracy of judgments by integrating different types of data related to similar phenomenon (Smith, 1975). Details in the research setting and the data collection method are described in the following section.[4]

[4] Golden-Biddle and Locke (1997, p.56) described how to use the methodology section in a novel way to capture the essence of Grounded Theory Building. I followed the procedure they described to portray the details of the organization in focus and valid reasons for theoretical sampling of this kind.

3.3. Research Method

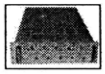
3.3.1. Research Setting

The current multi-method field study was conducted in a Canadian company, Protocase, Inc. (hereafter, Protocase), which specializes in the low-volume production of custom-made electrical component enclosures — a type of box that houses components such as printed circuit boards and connectors. Protocase's main products are listed in Table 3.1. Its main customers include research labs and new product development teams at large companies and research organizations that require enclosures for prototyping. Low-volume mechanical component manufacturers are also one of the major customers. They include Boeing, IBM, NASA (three divisions), UCLA, Stanford University and MIT. Protocase, which started production in 2002, now generates more than $1.5 million in annual sales in more than 40 U.S. states.

Protocase presents a compelling case for this study for two reasons. First, the company engages in a very interactive and heavy joint problem-solving process with its customers. Protocase employees constantly communicate with their users to develop a product that will satisfy both the users' needs and the company's manufacturing capacity. Second, there is a clear language difference between the manufacturer and their users. The manufacturer is heavily oriented in the mechanical engineering (ME) field while the customers are mainly electrical engineering (EE) or EE-related firms. In fact, all active technical and sales support personnel of the manufacturer are trained specifically in ME or management. Most of the customers are trained in EE and they order the enclosure to mount electrical components such as printed circuit boards and connectors that they

design. This existing language difference allowed me to focus on its function in the joint problem solving process in product design. As such, Protocase provides a rich empirical ground for developing a detailed picture of the joint problem-solving process between users and a manufacturer.

Table 3.1. Main Product Categories at Protocase, Inc.

Type of Product	Design Process	Example
Fully Custom Enclosures	Customers can design the custom enclosures, or the manufacturer can provide a design service utilizing information provided by the customers.	
Custom U-Shape Enclosures	Customers start with the template-based designs and build on to it. Templates are provided by the manufacturer.	
Custom Rackmount Enclosures	Customers start with the template-based designs and build on to it. Templates are provided by the manufacturer.	
Custom Mini-ITX Enclosures	Choose from one of the base Mini-ITX enclosures and customize by choosing options or start with the template-based designs and build on.	
Custom Panels and Brackets	Customers can design the custom panels and brackets, or the manufacturer can provide design service with the necessary information provided by the customers.	

Source: http://www.protocase.com

3.3.2. Data Collection

Data was gathered from three major sources: manufacturer interviews, user interviews, and communication data. The manufacturer and user interviews were critical to examine both the users' and the manufacturer's perspectives. They also provided rich contextual information on how language differences on each side impacts this problem-solving process. Combined with the verbal protocol analysis, user interviews were used to capture both the users' behavior and their thinking process during the design problem-solving stage. Communication data from the company database was also gathered in order to examine the general characteristics of the communication between the users and the manufacturer.

3.3.2.1. Manufacturer interviews

The objective of my interviews with the staff on the manufacturing site was to understand how they perceive the issues stemming from language differences during the collaborative user-manufacturer problem-solving process. I conducted interviews for two days at the manufacturer's site in Nova Scotia, Canada. Before visiting the site, the CEO of the company provided a list of professionals—from management to EE, ME and e-commerce—whom I could contact for the interviews. Seven informants from different domains were identified to obtain diverse perspectives on the joint problem-solving process. Details about the informants are provided in Table 3.2.

Each interview lasted an average of 60 minutes. The interviews were recorded during the session and later transcribed for analysis. The interview protocol was semi-structured in that there were some pre-set questions, but most questions were open-ended due to the various job specifications and perspectives of the interviewees.

Table 3.2. Informants at the Manufacturing Site

Informant's Position or Title	**Educational Background**	**Job Description**
CEO/Cofounder	Mechanical Engineering	Manages day-to-day operations. Make decisions on company's strategic directions.
Research Director/ Cofounder	Mechanical Engineering	Makes decisions on company's strategic directions.
Software Developer	Electrical Engineering	Develops and upgrade the product design software customized for case design
Technical Support	Mechanical Engineering	Handles technical issues that can't be resolved through sales support. Design cases using 3D CAD software.
Sales Support A	Management	Communicates with customers to receive orders, manage the orders, and engage in after sales activities (customer relationship management activities).
Sales Support B	Management	Communicates with customers to receive orders, manage the orders, and engage in aftersales activities.
Marketing/E-commerce	E-commerce	Manages company web site and the orders coming through the web site.

.3.3.2.2. User interview and verbal protocol analysis

The purpose of the user interviews was to investigate how users recognize and address the language differences. Two employees in the sales support[5] department identified a total of 19 major customers in Massachusetts as potential interview candidates. Interview invitations were sent out and six agreed to participate. Of these six people, four were selected for in-depth interviews and verbal protocol analysis. They were chosen to provide variance on the type of educational specialization (electrical or mechanical engineering), level of expertise in communication with Protocase, and level of expertise in using the Protocase Designer™ [6]. Theoretical sampling of this kind is well supported by the existing literature on Grounded Theory Building (Glaser & Strauss, 1967; Locke, 2001). Having variance in the sample allowed for the systematical investigation into the effect of language differences on the problem-solving process.

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[5] The employees had a better understanding of the users, which in turn informed me about the user selection for the interviews.

[6] Protocase Designer™ is simplified 3D CAD software specifically designed for case design. The software is close to the toolkit mechanism developed in other studies (Thomke & von Hippel, 2002; von Hippel & Katz, 2002). Since I focus on the collaborative problem-solving process and the impact of problem-solving language difference, I will not get into details of the toolkit mechanism. In this paper, the toolkit usage data were used for understanding user's problem-solving process. The toolkit mechanism in this paper is referred as simplified "3D CAD software" or "3D design software."

Table 3.3. Informants from the User-side

	Educational Background	**Job Specification**	**Previous experience working with the manufacturer**	**Previous experience using Protocase Designer™**	**Organization Type**	**Main Business**
A	Electrical Engineering	Build prototypes for Maritime Awareness System	Yes	Yes	Transportation Research Center	Government research center for transportation systems
B	Mechanical Engineering	Build prototypes and parts for the end-product	Yes	Yes	Equipment Manufacturer	Manufacturer of spin testing equipment and high speed drive Systems
C	Electrical Engineering	Software engineer	No	No	R&D Laboratory	Nonprofit R&D center for government & commercial research projects
D	Mechanical Engineering	Development of mechanical part of the product	No	No	Light Manufacturer	Manufacturer of interactive lighting and entertainment surface products

Each interview started with a verbal protocol analysis, which has been used extensively in experimental psychology research to investigate the nature of thinking and to "trace the intermediate steps of thought processes" (Ericsson & Simon, 1984, p.7). Such research has generated a solid empirical basis for insight into areas such as the nature of different reasoning strategies, the development of expert levels of performance, and the mechanisms employed in problem-solving (Newell & Simon, 1972). The verbal protocol analysis was aimed at overcoming the limitations of the introspective method by focusing on the externally observable thinking process (Ericsson, 1999). Before the beginning of the each session, subjects were instructed to verbalize their thinking process, and were given a chance to practice[7] the verbalization process for five minutes before the actual recording (Ericsson & Simon, 1984).

To capture the verbal protocol as well as the behavior during the design process, I observed the users using simplified 3D design software developed by Protocase. This software is called Protocase designer™, and is available at the company web site. I used a scan converter to convert the signals from the computer (SVGA format) to the NTSC format to be videotaped. All behaviors on the computer, including clicks and mouse point movements, were captured in the video. The corresponding audio was recorded separately and later synchronized with the video for analysis. Field notes were also taken while observing users' behavior on the computer and listening to their verbalizations.

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[7] The weakness and strength of the verbal protocol analysis should be noted. Not all thoughts that pass through one's mind are verbalized and some processing steps (thoughts) may be short-circuited with acquired skills. Various methods including the practice period before the actual analysis were identified to mitigate this weakness. However, persuasive evidence supports the validity of the thoughts that are verbalized (Ericsson & Simon 1993). In management studies, Schweiger (1983) studied the validity of the method in managerial decision-making, and concluded that the verbal protocol is a valid method to study managerial thinking and decision-making processes.

Immediately after each verbal protocol analysis, a semi-structured interview was conducted to gather information about the perception of language differences, the experience in designing a enclosure, experience working with the manufacturer (for experienced users only), and background information about the users (e.g. education, job specification). Some additional questions were also asked to clarify the findings from the observation in the verbal protocol analysis period.

3.3.2.3. Communication data

Emails were logged with full details of messages, including the text itself, and phone calls were logged with the summary of the conversation. The manufacturing company had a policy of recording all emails (incoming and outgoing) in the company's database. Phone calls were recorded as well but not as strictly as emails. A total of 2,365 email and phone calls were logged between March 2005 and March 2006. Of these, 97% were emails and only 3% were phone calls. All communication data was anonymized in order to protect the identity of the employees and the users.

.3.3.3. Data Analysis

For the coding procedure for the qualitative data collected from the user and the manufacturer interviews, I followed the coding procedure instructions for the qualitative data described in various sources (e.g. Golden-Biddle & Locke, 1997; Miles, 1979; Strauss, 1987). Each recorded interview was transcribed and analyzed to generate a meaningful interpretation of the phenomenon. I started with the open coding described in Strauss (1987) to identify main categories. Then I progressed to axial and selective coding to identify subcategories and their interrelationship and interdependence with the language differences between manufacturers and their customers in a customized product development process.

Verbal protocol data was analyzed using the method described in Ericsson and Simon (1984). Data was deconstructed into each step then compared to each user to identify whether there were any differences in the problem-solving process. Users' interview data was used as the secondary source to shed some light on each user's process.

3.4. Findings

From the multiple data sources, I found strong boundary effects during the joint problem-solving process between the users and the manufacturer. The findings are summarized here with specific examples provided in the following sections. First, the initial problem-solving language difference is observed during the early stage of the joint problem-solving process. This initial language difference is a two-sided effect that establishes the boundary between the users and the manufacturer. Second, both parties are reluctant to reveal their language incomprehension. Third, with an incomplete understanding of the problem-solving language, the users start to make assumptions. If these are congruent with reality, then the language difference may not cause a significant problem. But, if the assumptions are not congruent with reality, then this causes a significant problem as both sides continue to proceed with the product development process. This process model of what happens when the users and the manufacturer engage in a joint problem-solving process helps us to understand the nature of the boundary that exists between users and manufacturers. The role of the boundary object is also identified as an important mechanism that makes the process more effective as the collaborative problem-solving evolves.

3.4.1. Two-sided Problem-Solving Language Difference

The manufacturer's informants acknowledged some language differences between them and their product's users. Since they engage in a highly interactive problem-solving

process to devise a customized product, this issue becomes very important. One of the sales support personnel indicated that the problem usually surfaces when collaborating with novice users while it is less problematic to work with expert users. This language difference comes from the user's lack of understanding of the manufacturer's language, what is called *user-side language difference.*

> ***Sales support****: We always try to keep it in the back of our heads that we'll have to explain everything. If it's a more experienced user we can usually tell just by speaking with them a few minutes. Then we can start to use terms like sheet metal terms and fasteners, things like that. But if the person doesn't have that knowledge we'll explain that a fastener's a nut that's pressed into the box and you can put a standoff in it ... and things like that. We try to accommodate the new customer. We try to get through to them on their level.*

> ***User A****: There were some language issues. I think when we were talking about the case design, and they talked about some cutout it would be over my head. I'm just looking for really simple squares and circles typically and I ended up doing the DB9 connectors. At first, I didn't know what a U-shaped enclosure was, maybe because I'm not familiar with the industry, but I had no idea what it was. I imagined it was a U shaped tube or something. I didn't realize it was a box, like a clam shell box. But the first time I talked to them, they were pretty specific I wanted a 19 inch rack (mount) enclosure 3U high*[8]*, so it was. Other than a couple things, I had no idea what they were talking about. But it was more because of me not being in the industry and when I told them that, they made it simple. There was a little bit of a gap when I first started talking to them.*

[8] The 2U, 3U, etc. are all different sized rackmount enclosures; the U following the number is short for unit. The number indicates the size of the rackmount, 1U being the smallest rackmount and 7U being the biggest rackmount.

However, the communication issue has another dimension. Manufacturers also experience some difficulties understanding the user's language, which primarily evolves around the electrical engineering world. The manufacturer is a mechanical engineering company and most people are trained in mechanical engineering, not electrical engineering. Therefore, technical support and sales support personnel who often engage in the joint problem-solving process express a difficulty in understanding the user's problem-solving language. This is called *manufacturer-side language difference.*

> ***Technical Support**: Most times the difficulties come from the customers not knowing what they're doing and they expect us to be right up on the latest in the electronics world like they expect us to be familiar with every electronic component out there, which isn't the case because our technical support team is mechanical engineering based, not electrical engineering based. So eventually it would be good for us to get somebody electrical in here, but for now we just stay away from the electrical part of it and basically tell them to get us the dimensions for their components...*

Hence, the problem-solving language difference is a two-sided effect. This can be mitigated when users are trained in mechanical engineering and then engage themselves in the electrical engineering world for a long time, as we can see from the case of User D, or when the manufacturer hires a person[9] with an electrical engineering background and trains her/him in the mechanical engineering world. As we mentioned earlier, this type of gatekeeper can be very useful in translating across the boundary. But the existence of language difference is only the beginning of the process model that is identified in this

[9] In fact, the manufacturer hired a person that fits this profile after the interviews were done.

study. The problem-solving language difference clearly shows the existence of a boundary. But additional psychological factors make this boundary more prominent.

.3.4.2. Reluctance to Reveal Language Incomprehension

What intensifies the effect of the boundary is the fact that both the users and the manufacturer are reluctant to reveal that they do not clearly understand what the other party is trying to convey during communication.

> ***Technical Support**: Most times we'll have a difficulty because somebody will call and say, "I'm mounting a 256 3.7 board with this," and I don't know what they're talking about, right? And they don't understand why I don't know because first of all, I don't come flat out and tell them I'm not an electrical person because it's not good to do.*

The technical support staff's basic response is not to reveal their language incomprehension when they encounter a language difference. The specific reason is not entirely clear from this example. But from the remarks in the previous section, I can speculate that the customer's expectation that the manufacturer will be 'technically bilingual' might have caused this reluctance to reveal his or her language incomprehension. Manufacturers usually put great effort into creating customer satisfaction. From the interviews, the CEO of this company mentioned several times that Protocase heavily focuses on customer satisfaction due to the nature of their business of developing customized products. The burden of satisfying customers may have driven the technical support staff to hide their language incomprehension. But the pure economic

reason for their reluctance does not satisfactorily explain the phenomenon observed here, since it could be more economical for the technical support to reveal their language incomprehension and avoid possible future errors.

This reluctance to reveal language incomprehension is not limited to the manufacturer. Users also show the same attitude. Sometimes, they behave somewhat strangely by closing the conversation abruptly when they do not understand what the manufacturer's engineer is trying to convey.

> ***Sales support**: I guess it was a few months ago...someone would call and we'd ask what fasteners they were using and similar questions about their preferences. And people would be sitting there wondering what we were talking about. They'd get mad. They want to get off the phone. And I think with anyone, if they're on the phone and they don't understand what the other person is saying, your human instinct is to end the call.*

At first glance, this two-sided reluctance to reveal the incomprehension of the problem-solving language and reluctance to seek help seems quite unreasonable. After all, understanding each other's language and then proceeding with the joint problem-solving process can lead to a successful product development for both sides. However, existing literature identifies some costs related to the help seeking behavior in these joint problem-solving situations. First, help seeking implies incompetence by revealing that there is a gap in one's knowledge (Lee, 1997: p. 339). Since expertise and problem-solving skills are important sources of gaining power in an organization (e.g. Katz & Allen, 1985), revealing one's incompetence reduces one's power by increasing dependence on the person who has more expertise in the area where help is sought

(Emerson, 1962). Second, as Lee (1997) found in her study, help-seeking is tied to 1) one's own self-image and 2) one's image presented to others in a social setting. Revealing that one does not understand something may not only undermine one's positive self-image, but it can also create a negative image in other people's eyes.

At the boundary between the users and the manufacturer, both explanations about the power and the management of the impression seem to hold true. The user-manufacturer relationship is based on the transaction that the buyer seeks outside of an organization's hierarchy. This market transaction is based on a contract and a negotiation price. Therefore, one can argue that by showing one's expertise and decreasing one's dependence on another for technical help, one could create a positive advantage for oneself on the transaction price if a contract has yet to be negotiated. Likewise, maintaining a positive image of oneself is not limited to the typical organizational setting. People are sensitive about how they are viewed by others and presented to others. These concepts can explain users and manufacturers' reluctance to admit that they do not understand problem-solving language to a certain degree.

A question that is as important as the cause and motivation of this reluctance is, "what is the effect of this reluctance?" Edmondson (1999) showed that when there is a shared belief that a team is safe for interpersonal risk-taking, this can create a better learning experience, which in turn will lead to a better team performance. What if the atmosphere is not conducive to share risks or to safely reveal knowledge gaps? What if there is a strong boundary between the help seeker and the potential help giver? How would these conditions affect the outcome of joint problem-solving? These questions are empirical in nature, and they should be examined in further detail. But first in the

following section, I report that the reluctance to reveal language incomprehension and an avoidance to seek help can lead to assumption-based behavior that can impair the effectiveness of the joint problem-solving process.

3.4.3. Making Assumptions without Validation

What do individuals do when they cannot understand what another person is saying, but are reluctant to reveal this incomprehension? Several options are available. People can search for more information via secondary sources such as a company's web site and technical document, or ask someone they are familiar with for help (Cross, Borgatti, & Parker, 2001). But given the joint problem-solving situation, the constant and direct flow of knowledge is necessary between the users and the manufacturer in order to increase the efficiency and effectiveness of the product development process.

I found that users tend to make assumptions when they encounter language differences and incomprehension problems, but proceed with their work anyways without attempting to validate their assumptions. This is a much more passive way to respond to language incomprehension rather than to directly seek information.

> ***User A:*** *Before we got to Protocase we had gotten generic 19" enclosures. We put them together, they were pretty flimsy and we couldn't find anything out there that was nice and solid. And one of the things we like to do when we do installations when we put it somewhere, we don't want people to pick it up and we don't want it to flop like aluminum. We just assumed that their standard setup would be, not flimsy, but we would need*

something a little thicker than the standard gauge[10]*. We were wrong. When we got it, it was very heavy... I was making an assumption on the thickness of the steel, the case itself. At the end, it was a lot thicker than I thought it would be.*

User A's experience is a good example of this process. Protocase uses a very specific unit, gauges, to indicate the thickness of steel or stainless steel. In fact, the question about the steel's thickness is frequently asked in the process; hence, it is at the top of the frequently asked questions (FAQs) section of the company's web site. But User A failed to consider that this information might be available and seek the correct information from the manufacturer. The specialized problem-solving language that the manufacturer uses to effectively communicate with its in-house staff actually functions as a barrier for the user to effectively solve the problem. User A in this case did not understand what the standard gauge was or the type of gauge he wanted because the manufacturer used its own problem-solving language (e.g. gauges). When this language incomprehension is not acknowledged and resolved, the user starts to make assumptions in order to proceed with his or her work. The user's reluctance to reveal his or her lack of comprehension thereby hinders the direct communication process that could help resolve the problem, and it intensifies the boundary effect between the user and the manufacturer. The outcome of this assumption-based behavior can be either positive or negative, depending on the

[10] Gauge is the measurement used for thickness of material in mechanical engineering field. The conversion table for gauges and inches are shown here.

Gauge #	Plain Steel	Stainless Steel
11	0.120 in	0.125 in
12	0.105 in	0.109 in
14	0.075 in	0.078 in
16	0.060 in	0.063 in
18	0.048 in	0.050 in
20	0.036 in	0.038 in
22	0.030 in	0.031 in
24	0.024 in	0.025 in

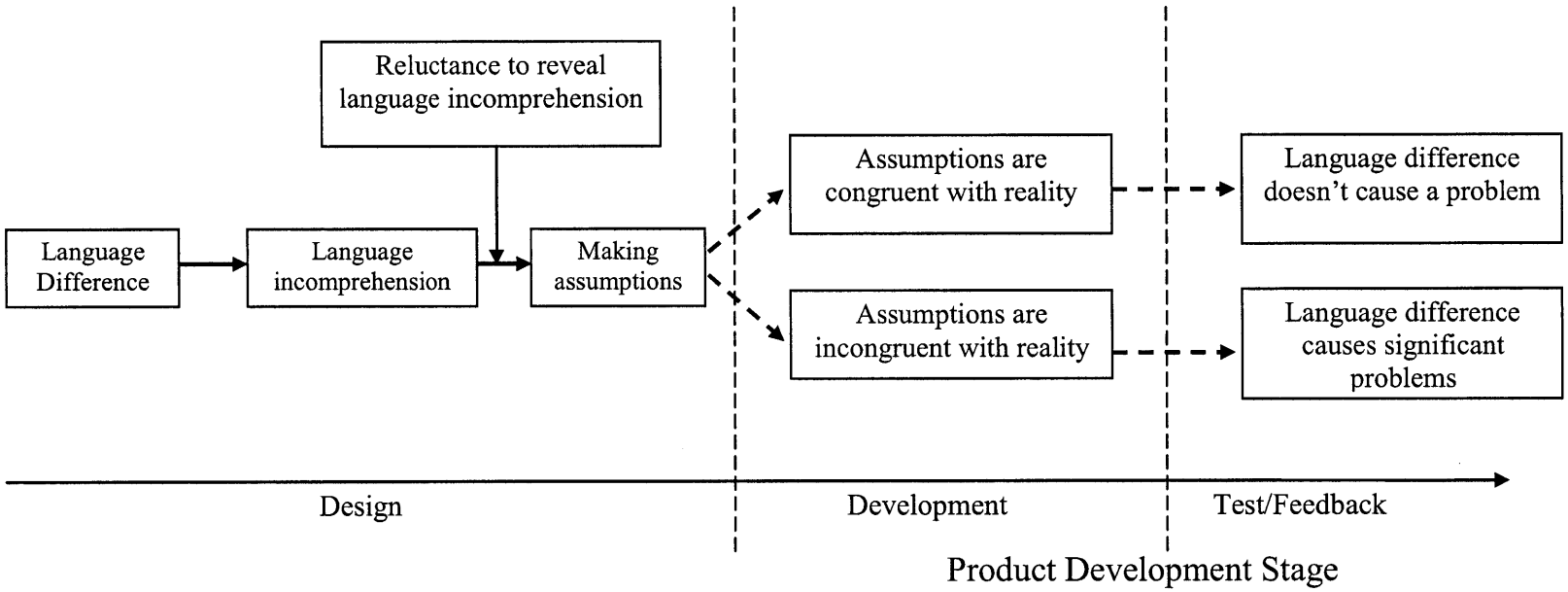
(Source: http://www.protocase.com/www/links/faq.asp.)

congruence between the assumption and reality. In the case I presented above, the assumption on the thickness of the material was far from reality; therefore, User A experienced a significant difference between the initial assumption and the outcome. But users can get lucky in some cases when their assumptions are congruent with the reality. However, the unlucky cases could be systematically reduced if users and manufacturers had a better understanding of the cross-boundary communication process and implemented more effective communication and learning mechanisms.

3.4.4. A Process Model of User-Manufacturer Joint Problem-Solving in New Product Development

The user-manufacturer problem-solving process in the product development stage can be summarized in Figure 3.2. First, there is the initial problem-solving language difference during the early stage of the joint problem-solving process. This difference is a two-sided effect that sets up the boundary between the users and the manufacturer, and leads to a language incomprehension between the two parties. Second, they are both reluctant to reveal their language incomprehension. Third, with an incomplete understanding of the problem-solving language, the users start to make assumptions. All these three steps happen in the design stage. If the assumption is congruent with reality in the product development stage, then the language difference may not cause a significant problem in the test/feedback stage. But, if the assumption is not congruent with the reality, then this faulty assumption is likely to cause a significant problem as both sides continue to proceed with the product development process.

Figure 3.2. A Process Model of User-manufacturer Joint Problem-solving



The process described here can be better understood by comparing it with the single and the double-loop learning process (Argyris, 1982; Argyris & Schön, 1978). Learning in organizations has been studied in two schools of thought: as an outcome and as a process (Edmondson, 1999; Levitt & March, 1988). The former emphasized the outcome of learning by focusing on routine-based, history-dependent, and target-oriented learning (Levitt & March, 1988). Learning in this case is done by encoding inferences from past experience and storing it in routines. Routines also affect future learning by guiding the search behavior of organizations. The other school of thought emphasized the process of learning that has an ongoing, interactive, and sense-making nature (Argyris & Schön, 1978). This school focused on learning as an error-detection mechanism, challenging the fundamental norms and values of organizations.

The learning mechanism that emphasizes the error detection mechanism fits well with the early joint problem-solving process between the users and the manufacturer. Argyris and Schön (1978) explained the learning process using the concept of the single- and the double-loop learning. Single-loop learning is the process that can detect an error and correct the underlying assumptions. Double-loop learning not only changes the assumptions, but also alters the fundamental beliefs and values. This process focuses on the individuals and their cognitive thinking while they are engaged in the learning process. Single- and double-loop learning processes are also very interactive in that one's assumption and fundamental values are challenged by others who are engaged in the process.

Users and manufacturers have a strong boundary between them when they engage in the problem-solving process; therefore, both the single and the double-loop learning

mechanisms are crucial in bridging boundaries. However, the problem-solving process described in Figure 3.2 lacks both of these mechanisms. Due to the strong boundary effect caused by economic and psychological reasons, both the users and the manufacturer do not want to reveal their language incomprehension and potentially wrong assumptions. Even if they express their lack of comprehension, it will usually take many back-and-forth conversations to figure out what exactly the other party is saying. Without the error-detection mechanism, assumption behavior can lead to many subpar outcomes that might cause serious problems for both the users and the manufacturer.

What the manufacturer needs to do is actually two-folded. The manufacturer can implement a mechanism that can check the assumptions that the users make (*error-detection mechanism)*. Then, the manufacturer can also try to change the basic values and attitudes towards the learning (*attitude-altering mechanism*). The following comment from User D indicates the importance of changing the users' values.

> ***User D**: Sometimes, I might have been too quick to assume that I understood something and didn't know the impact of making so many assumptions that some of those assumptions were going to turn out to be errors or mistakes on my part. So what I've learned over the years is it's kind of like a little inner voice saying, "Wait a minute I'm making an assumption, I really don't understand this, let me ask more questions."*

User D is very experienced mechanical engineer who has spent many years working with electrical engineers. His fundamental view on asking and seeking help has changed over a long period of time spent in collaborative design processes, which in turn makes error detection much more feasible. If the manufacturer uses the error detection

mechanism, which can validate assumptions without altering users' fundamental values and attitudes towards the assumed behavior, this will only enable the single-loop learning. Users will keep making assumptions on what they do not understand during the joint problem-solving process without altering their fundamental view on their assumptions. Even if the error-detection mechanism can identify some of the assumptions made, it cannot detect all the possible wrong assumptions that could be generated during the process. Assumptions are made in an inherently cognitive process and cannot be detected unless they are externalized and communicated. Therefore, the manufacturer should approach the joint problem-solving process as both single- and double-loop learning mechanisms, and should attempt to remedy the uncomfortable atmosphere that is described in the presented process model. The manufacturer should explain to the users that it is necessary to reveal language incomprehension or gaps in knowledge for an efficient design process and successful product design. The company should also recognize that revealing language incomprehension problems is crucial to understand users' problem-solving language; therefore, unnecessary assumptions should not be made during the process.

3.5. Discussion

3.5.1. How can Language Difference be Mitigated?

Language boundary is bridged via constant social interaction (Nonaka & Takeuchi, 1995). Recent research identifies various ways in which interaction can mitigate the boundary. Working across different communities is made possible by the translation of different meanings through boundary-spanning individuals (Brown & Duguid, 1991; Hargadon & Sutton, 1997; Yanow, 2004), shared language (Bechky, 2003), or boundary objects (Star & Griesemer, 1989). Brown and Duguid (1991) explained the role of a copy machine service technician as the boundary spanner who brings in the customer's experience in the form of story-telling. In this case, the local meanings and interpretations are filtered by the service technician who shares them with other organizational members. Hargadon and Sutton (1997) explained how individual 'brokers' store different experience in product development settings, and use it meaningfully in a newly defined product development context. Yanow (2004) also described the role of the delivery men who delivers baked goods directly to customers. In this case, the delivery men interpret and store valuable customer feedbacks and bring them back to the company managers. In these studies, the individuals who cross the boundary translate the meaning across different communities and work as the bridging mechanism.

In some cases, the boundary is bridged by the creation of a new meaning that can be shared across the boundary. On the production floor, Bechky (2003) discovered differences among design engineers, machine assemblers, and technicians in their work,

their conceptualization of a product, and their language (p.318). Design engineers conceptualize the product as schematic and they focus on the form, fit, and the function of the product. They reside in the design world and speak the language of engineering design (mainly drawings). Machine assemblers understand the product as spatio-temporal and processual, and speak mostly the language of machine. Technicians are interested in the manufacturability of the product and communicate both the engineering drawing language and the language of machine. In order to communicate between these disparate occupational communities, individuals use a tangible definition to create a common ground that can move the conversations forward. In the examples given in this study, individuals refer to the physical settings – such as pumps, electrode slide, chamber chips, plasma starter, or short cable – to create common tangible definitions and to explain what is contextual and embedded in their own work practices in terms that the listeners can understand.

Physical settings are important because individuals' knowledge is contextualized in the surroundings. As Tyre and von Hippel (1997) show in their study, a certain physical setting also provides a venue for learning new things that cannot be found in other settings. In this study, engineers of a new process machine go back and forth between the user's plant where the machine is located and the lab where they can run experiments, talk to experts, and collaborate with mechanical specialists. The engineers cannot see the problem until they actually see it in the physical setting and gather the embedded clues.

In some cases, a boundary object, not a person, works as the translation mechanism for the different meaning. The use of standardized and common boundary objects, such as specimens, field notes, and maps of particular territories, helped different stakeholders

of Berkeley's Museum of Vertebrate Zoology to view things on their own terms (Star & Griesemer, 1989). In the product design process, boundary object such as design sketches or drawings became reference points for explanations and externalizations of thoughts. Eckert and Stacey (2000) show how design sketches of knitwear helped to communicate original ideas to other participants in the design process. In this example, the boundary object carries the original inspirations and brings different additional design ideas from the participants.

3.5.2. A Vignette of Local Learning Process

In this section, I present a vignette of the local learning process between the engineer at the manufacturing company and the users. Once the manufacturer and the users engaged in the product design process, I could observe that the local learning process can actually mitigate the language difference. Previously I gave the example of how User A made assumptions on the thickness of the material of the enclosures, and received the enclosures later only to find out that it was not the thickness he wanted. The vignette I try to show in this section is the case in which this very same problem is resolved through the local and interactive learning process.

> *From: Brett <mfr@protocase.com> To: Mike*
> *Sent at: 11/29/2005 3:03:30 PM*
> *Hi Mike, I will have a quote to you very shortly. I wouldn't recommend an 11 guage front panel unless it is essential because it will add significantly to your*

cost. Also we are unable to work with 11 guage stainless so the quote will be for an enclosure with 11 guage plain steel front panel only. The brace is not a standard product however if you decide to order you will receive a 3D model within 24 hours of your enclosure with brace for your approval. ……

When Mike (User) gave the initial design specifications to Brett (Sales Support), Brett basically told Mike that the 11 guage front panel is quite expensive. Brett also told Mike that only the 11guage plain steel can be used for front panel. At this point, it is not shown whether Mike understands the exact meaning of the unit of the 11 guage. Brett is comfortable using the word, since that is the process (related to the thickness of material) that he is familiar with.

From: Mike [mailto:mike@stateuniv.edu]
Sent: Wednesday, November 30, 2005 7:51 PM To: mfr@protocase.com
Subject: RE: Quote
Brett;
I have measured a few of the rack enclosures we currently have and I think 16 gauge plain steel would work. However, all the cases here have a 1/8" inch front. I think we should go back to the original quote for plain steel and quote with both fronts a 14 gauge and a 11 gauge. A question I have also is what the thickness of the 14 gauge is. If it is really close to .100" it might work out. Also, get the drawing of the brace to me so I can ok it, and I believe I will order it this week. I just found out also that I need to order another rack enclosure that is 7" tall. Could you please send me a template for this as well.
Thanks
Mike, State University

Mike approximates the 14 guage at .1". By trying to approximate what he does not know exactly, he tries to draw the answer from Brett about what exactly the 14 guage means. What is important here is that the user is still reluctant to clearly state that he doesn't understand the exact measure for the 14 guage. Instead, he attracts the attention of sales support by saying he has a question. Then he approximates the guage to see if it is the correct number or not. If he did not mention this question even in an indirect way, this misunderstanding of the "14 guage" could have led to a wrong assumption and led to a product that does not meet the requirement of the user.

What also matters in this situation is that the "14 guage" is an important user requirement. Manufacturer needs to address this question since it will be an important user input that should be included in the product features. The way that the manufacturer responds in the following email shows that this issue of the "14 guage" is a really important problem and should be resolved.

> *From: Brett <mfr@protocase.com> To: Mike [mailto:mike@stateuniv.edu] Sent at: 12/1/2005 2:13:02 PM*
> *Hi Mike, I have forwarded your template request to tech support. The thickness of 14 gage plain steel .075". I can provide a quote for an enclosure with an 11 gage front panel but it tends to add to your price. I will send the quote to you shortly. If you have any questions, please feel free to respond to this email and I will do whatever I can to assist you.*
> *Thanks,*
> *Brett*

Brett responds to Mike with the correct answer. Unlike User A shown in the previous example, Mike successfully reconciled his incomprehension of the "guage" – the manufacturer's problem-solving language.

.3.5.3. What Needs to be Transferred from User to Manufacturer? Things That Are Interdependent

The information that needs to be transferred is limited and bound by the interdependencies between the two parties involved in joint problem-solving. The one-to-one match between the signified and the signifier – in other words, the understanding of the language on the receiver's part - only has to apply to the information that has to be transferred. For example, the electrical engineer who is buying a Protocase enclosure does not have to tell Protocase what the circuit does outside "a range of interdependence." Interdependence on any variable often holds only within a range. Thus, the circuit has attributes that might affect Protocase. For example, if the circuit demands a lot of power or heats up a lot, this has implications for what Protocase supplies. To understand the concept of an interdependence range, a simpler example is presented here. Imagine a design engineer who designs a bridge. Beyond the certain amount of pressure the cars can put on the bridge – after considering other important factors that affect the pressure - there is no interdependence between the vehicles and the design of a bridge until they reaches the weight limit specified for the bridge. So although the interdependence matters between the weight of vehicles and the bridge design, the more important thing is the range of interdependence. Since the interdependencies will

not always be clear to the user *ex ante*, there will be trial-and-error and iterative problem-solving to identify interdependencies and related problems.

3.6. Conclusions

In this chapter, I analyze the joint problem-solving process between users and a manufacturer, and generated a process model that describes the nature of a collaborative problem-solving process that occurs across a strong boundary. In this process model, the strong boundary effect is attributed to the reluctance of the users and the manufacturing engineers to reveal language incomprehension and their unwillingness to seek additional help. This study focuses on the nature of language differences between users and manufacturers and explains how the differences can be mitigated by local trial-and-error learning. The key to this process is to recognize that the information that needs to be transferred is limited and bound by the interdependencies between the two parties involved in the joint problem-solving process. Investigation into the communication channel between the seemingly disparate groups – a manufacturer and its users – reveals that the language boundary can be mitigated by the local learning process based on the technical interdependencies between user requirements and technological implementation.

Further studies are required to shed light on the collaborative problem-solving process at the boundaries of firms. More and more problem-solving processes are occurring at the boundaries of the firms, often encompassing people inside and outside the firm. Business-to-business (B-to-B) commerce based on customized products and services are increasing as well as outsourcing, which involves a great deal of problem-solving between people inside and outside the firm.

In my future research, I plan to expand the current study and further investigate the issues presented in this chapter. In this chapter, the problem-solving language difference is conceptualized and qualitatively observed. Since the problem-solving language and the interaction between users and manufacturers occur at both the individual and organizational level, I need to gather additional data on these issues to empirically test the process model presented in this paper.

Designing a new product is a complex process that involves many different stakeholders both inside and outside the firm. A holistic view of this process is needed to view users as an important source of information and input for product design and development. Users should be part of the problem-solving process rather than as the final consumers of the process.

References

Alexander, C. 1964. ***Notes on the Synthesis of Form***. Cambridge, MA: Harvard University Press.

Allen, T. 1966. Studies of the Problem-Solving Process in Engineering Design. ***IEEE Transactions on Engineering Management***, EM-13(2): 72-83.

Allen, T. J. 1977. ***Managing the Flow of Technology: Technology Transfer and the Dissemination of Technological Information within the R&D Organization***. Cambridge, Mass.: MIT Press.

Allen, T. J., Tushman, M. L., & Lee, D. M. S. 1979. Technology-Transfer as a Function of Position in the Spectrum from Research through Development to Technical-Services. ***Academy of Management Journal***, 22(4): 694-708.

Ancona, D. G. & Caldwell, D. F. 1992. Bridging the Boundary - External Activity and Performance in Organizational Teams. ***Administrative Science Quarterly***, 37(4): 634-665.

Anderson, J. R. 2000. ***Cognitive Psychology and Its Implications*** (5th ed.). New York: Worth Publishers.

Anzai, Y. & Simon, H. A. 1979. Theory of Learning by Doing. ***Psychological Review***, 86(2): 124-140.

Argyris, C. & Schön, D. A. 1978. ***Organizational Learning***. Reading, Mass.: Addison-Wesley Pub. Co.

Argyris, C. 1982. ***Reasoning, Learning, and Action: Individual and Organizational*** (1st ed.). San Francisco: Jossey-Bass.

Arrow, K. J. 1969. Classificatory Notes on the Production and Transmission of Technological Knowledge. ***American Economic Review***, 59(2): 29-35.

Barthes, R. 1967. ***Elements of Semiology***. London: Cape.

Bechky, B. A. 2003. Sharing Meaning across Occupational Communities: The Transformation of Understanding on a Production Floor. ***Organization Science***, 14(3): 312-330.

Brown, J. S. & Duguid, P. 1991. Organizational Learning and Communities of Practice: Toward a Unified View of Working, Learning, and Innovation. ***Organization Science***, 2(1): 40-57.

Brown, S. L. & Eisenhardt, K. M. 1995. Product Development - Past Research, Present Findings, and Future-Directions. ***Academy of Management Review***, 20(2): 343-378.

Bucciarelli, L. L. 2002. Between Thought and Object in Engineering Design. ***Design Studies***, 23: 219-231.

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

Christensen, C. M., Cook, S., & Hall, T. 2005. Marketing Malpractice - the Cause and the Cure. ***Harvard Business Review***, 83(12): 74-+.

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

Clark, K. B. & Wheelwright, S. C. 1993. ***Managing New Product and Process Development: Text and Cases***. New York: Free Press.

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

Collins, A. M. & Quillian, M. R. 1969. Retrieval Time from Semantic Menory. ***Journal of Verbal Learning and Verbal Behavior***, 8: 240-247.

Conrad, C. 1972. Cognitive Economy in Semantic Menory. ***Journal of Experimental Psychology***, 92: 149-154.

Cooper, R. G. 1990. Stage-Gate Systems - a New Tool for Managing New Products. ***Business Horizons***, 33(3): 44-54.

Cross, R., Borgatti, S. P., & Parker, A. 2001. Beyond Answers: Dimensions of the Advice Network. ***Social Networks***, 23(3): 215-235.

Cusumano, M. A. & Nobeoka, K. o. 1998. ***Thinking Beyond Lean: How Multi-Project Management Is Transforming Product Development at Toyota and Other Companies***. New York: Free Press.

Cyert, R. M. & March, J. G. 1963. ***A Behavioral Theory of the Firm***. Englewood Cliffs, N.J.: Prentice-Hall.

Cyert, R. M. & March, J. G. 1992. ***A Behavioral Theory of the Firm*** (2nd ed.). Cambridge, Mass., USA: Blackwell Business.

DiBona, C., Ockman, S., & Stone, M. 1999. ***Open Sources: Voices from the Open Source Revolution*** (1st ed.). Beijing; Sebastopol, CA: O'Reilly.

Dougherty, D. 1990. Understanding New Markets for New Products. ***Strategic Management Journal***, 11: 59-78.

Dougherty, D. 1992. Interpretive Barriers to Successful Product Innovation in Large Firms. ***Organization Science***, 3(2): 179-202.

Duncker, K. 1945. ***On Problem-Solving*** (L. S. Lees, Trans.). Washington, D.C.: The American psychological association.

Eckert, C. & Stacey, M. 2000. Sources of Inspiration: A Language of Design. ***Design Studies***, 21(5): 523.

Edmondson, A. 1999. Psychological Safety and Learning Behavior in Work Teams. ***Administrative Science Quarterly***, 44(2): 350-383.

Emerson, R. 1962. Power-Dependence Relations. ***American Sociological Review***, 27: 31-40.

Ericsson, K. A. & Simon, H. A. 1984. ***Protocol Analysis: Verbal Reports as Data***. Cambridge, Mass.: MIT Press.

Ericsson, K. A. 1999. Expertise. In R. A. Wilson & F. C. Keil (Eds.), ***The Mit Encyclopedia of the Cognitive Sciences***: cxxxii, 964 p. Cambridge, Mass.: MIT Press.

Frischmuth, D. & Allen, T. 1969. A Model for the Description and Evaluation of Technical Problem Solving. ***IEEE Transactions on Engineering Management***, Em-16(2): 58-64.

Galison, P. 1997. ***Image and Logic: A Material Culture of Microphysics***. Chicago: University of Chicago Press.

Glaser, B. & Strauss, A. 1967. ***The Discovery of Grounded Theory: Strategies of Qualitative Research***. London: Wiedenfeld and Nicholson.

Golden-Biddle, K. & Locke, K. D. 1997. ***Composing Qualitative Research***. Thousand Oaks, Calif.: Sage Publications.

Griffin, A. & Hauser, J. R. 1993. The Voice of the Customer. ***Marketing Science***, 12(1): 1-27.

Hargadon, A. & Sutton, R. I. 1997. Technology Brokering and Innovation in a Product Development Firm. ***Administrative Science Quarterly***, 42(4): 716-749.

Katz, R. & Allen, T. J. 1985. Project Performance and the Locus of Influence in the R-and-D Matrix. ***Academy of Management Journal***, 28(1): 67-87.

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

Landes, D. S. 2000. ***Revolution in Time: Clocks and the Making of the Modern World*** (Rev. and enl. ed.). Cambridge, MA: Harvard University Press.

Larkin, J., Mcdermott, J., Simon, D. P., & Simon, H. A. 1980. Expert and Novice Performance in Solving Physics Problems. ***Science***, 208(4450): 1335-1342.

Lee, F. 1997. When the Going Gets Tough, Do the Tough Ask for Help? Help Seeking and Power Motivation in Organizations. ***Organizational Behavior and Human Decision Processes***, 72(3): 336-363.

Leonard-Barton, D. 1992. Core Capabilities and Core Rigidities - a Paradox in Managing New Product Development. ***Strategic Management Journal***, 13: 111-125.

Leonard-Barton, D. 1995. ***Wellsprings of Knowledge: Building and Sustaining the Sources of Innovation***. Boston, Mass.: Harvard Business School Press.

Leonard, D. & Rayport, J. F. 1997. Spark Innovation through Empathic Design. ***Harvard Business Review***, 75(6): 102-.

Levitt, B. & March, J. G. 1988. Organizational Learning. ***Annual Review of Sociology***, 14: 319-340.

Locke, K. D. 2001. ***Grounded Theory in Management Research***. London; Thousand Oaks, Calif.: Sage Publications.

Mandler, J. M. & Ritchey, G. H. 1977. Long-Term-Memory for Pictures. ***Journal of Experimental Psychology-Human Learning and Memory***, 3(4): 386-396.

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

Marshall, S. P. 1995. ***Schemas in Problem Solving***. Cambridge [England]; New York, NY: Cambridge University Press.

Miles, M. B. 1979. Qualitative Data as an Attractive Nuisance - Problem of Analysis. ***Administrative Science Quarterly***, 24(4): 590-601.

Moenaert, R. K., Demeyer, A., Souder, W. E., & Deschoolmeester, D. 1995. R-and-D Marketing Communication During the Fuzzy Front-End. ***Ieee Transactions on Engineering Management***, 42(3): 243-258.

Newell, A. & Simon, H. A. 1972. ***Human Problem Solving***. Englewood Cliffs, N.J.: Prentice-Hall.

Nonaka, I. o. & Takeuchi, H. 1995. ***The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation***. New York: Oxford University Press.

Owen-Smith, J. & Powell, W. W. 2004. Knowledge Networks as Channels and Conduits: The Effects of Spillovers in the Boston Biotechnology Community. ***Organization Science***, 15(1): 5-21.

Pawlowski, S. D. & Robey, D. 2004. Bridging User Organizations: Knowledge Brokering and the Work of Information Technology Professionals. ***Mis Quarterly***, 28(4): 645-672.

Pisano, G. P. 1990. The Research-and-Development Boundaries of the Firm - an Empirical-Analysis. ***Administrative Science Quarterly***, 35(1): 153-176.

Pisano, G. P. 1996. Learning-before-Doing in the Development of New Process Technology. ***Research Policy***, 25(7): 1097-1119.

Polanyi, M. 1966. ***The Tacit Dimension***. Garden City, New York: Doubleday & Company, Inc.

Powell, W. W., Koput, K. W., & SmithDoerr, L. 1996. Interorganizational Collaboration and the Locus of Innovation: Networks of Learning in Biotechnology. ***Administrative Science Quarterly***, 41(1): 116-145.

Quillian, M. R. 1966. ***Semantic Memory***. Cambridge, MA: Bolt, Beranak and Newman.

Rosenberg, N. 1982. ***Inside the Black Box: Technology and Economics***. Cambridge [Cambridgeshire]; New York: Cambridge University Press.

Rumelhart, D. E. & Ortony, A. 1976. The Representation of Knowledge in Memory. In R. C. Anderson & R. J. Spiro & W. E. Montague (Eds.), ***Semantic Factors in Cognition***. Hillsdale, NJ: Erlbaum.

Saussure, F. d. 1959. ***Course in General Linguistics***. New York: Philosophical Library.

Schweiger, D. M. 1983. Is the Simultaneous Verbal Protocol a Viable Method for Studying Managerial Problem-Solving and Decision-Making. ***Academy of Management Journal***, 26(1): 185-192.

Simon, H. A. 1973. The Structure of Ill Structured Problems. ***Artificial Intelligence***, 4: 181-201.

Simon, H. A., Dantzig, G. B., Hogarth, R., Plott, C. R., Raiffa, H., Schelling, T. C., Shepsle, K. A., Thaler, R., Tversky, A., & Winter, S. 1987. Decision-Making and Problem-Solving. ***Interfaces***, 17(5): 11-31.

Smith, H. W. 1975. ***Strategies of Social Research: The Methodological Imagination***. Englewood Cliffs, NJ: Prentice Hall.

Star, S. L. & Griesemer, J. R. 1989. Institutional Ecology, Translations and Boundary Objects - Amateurs and Professionals in Berkeleys-Museum-of-Vertebrate-Zoology, 1907-39. ***Social Studies of Science***, 19(3): 387-420.

Strauss, A. L. 1987. ***Qualitative Analysis for Social Scientists***. Cambridge [Cambridgeshire]; New York: Cambridge University Press.

Thomke, S. & von Hippel, E. 2002. Customers as Innovators - a New Way to Create Value. ***Harvard Business Review***, 80(4): 74-.

Thomke, S. 2003. R&D Comes to Services - Bank of America's Pathbreaking Experiments. ***Harvard Business Review***, 81(4): 70-.

Thomke, S. H. 1998. Managing Experimentation in the Design of New Products. ***Management Science***, 44(6): 743-762.

Tushman, M. L. 1977. Special Boundary Roles in Innovation Process. ***Administrative Science Quarterly***, 22(4): 587-605.

Tushman, M. L. 1978. Technical Communication in R and D Laboratories - Impact of Project Work Characteristics. ***Academy of Management Journal***, 21(4): 624-645.

Tushman, M. L. & Katz, R. 1980. External Communication and Project Performance - an Investigation into the Role of Gatekeepers. ***Management Science***, 26(11): 1071-1085.

Tyre, M. J. & von Hippel, E. 1997. The Situated Nature of Adaptive Learning in Organizations. ***Organization Science***, 8(1): 71-83.

Ulrich, K. T. & Eppinger, S. D. 2004. ***Product Design and Development*** (3rd ed.). Boston: McGraw-Hill/Irwin.

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

von Hippel, E., Thomke, S., & Sonnack, M. 1999. Creating Breakthroughs at 3m. ***Harvard Business Review***, 77(5): 47-.

von Hippel, E. & Katz, R. 2002. Shifting Innovation to Users Via Toolkits. ***Management Science***, 48(7): 821-833.

Williamson, O. E. 1991. Comparative Economic-Organization - the Analysis of Discrete Structural Alternatives. ***Administrative Science Quarterly***, 36(2): 269-296.

Yanow, D. 2004. Translating Local Knowledge at Organizational Peripheries. ***British Journal of Management***, 15: S9-S25.

CHAPTER 4: LEARNING-BY-INTERACTION

4.1. Introduction

In innovation studies, the issue of whether firms should look outside their boundaries has received much scholarly attention. The majority of literature on this topic focuses on the mechanisms that firms use to innovate from within and how they fail to turn their attention to the outside realm (Leonard-Barton, 1992; Levitt & March, 1988; March & Simon, 1958). But many firms do search for knowledge outside their boundaries and benefit from the diverse ideas, experiences and perspectives unavailable from within (Owen-Smith & Powell, 2004; Powell, Koput, & SmithDoerr, 1996).

While traditional innovation and organizational studies have looked at the collaborative efforts in the new product development process *inside* the firm, there have been comparatively few studies on the micro process of learning *between* a firm and its customers (Brown & Eisenhardt, 1995; Pisano, Bohmer, & Edmondson, 2001). As the dynamic capability theory posits, firm-specific skills, processes, organizational structures, and capabilities drive a firm's competitive advantages (Eisenhardt & Martin, 2000; Teece, 2007; Teece, Pisano, & Shuen, 1997). Learning is one of the central mechanisms of this firm-specific capability (Hayes, Wheelwright, & Clark, 1988; Pisano, 1994). The learning that occurs between a firm and the users of its products and services can be a key differentiating factor between a firm and its competitors if this kind of learning positions a firm on a more efficient or faster learning curve. In today's fast-changing business environment, the capability to glean, incorporate, and innovate based on what users need is directly related to achieving a competitive advantage (Prahalad & Ramaswamy, 2004; Teece, 2007).

Today's economic landscape is changing rapidly as well. The traditional clear boundary between learning-by-doing within the firm and learning-by-using that typically happens outside of the firm has become blurry due to the decreasing cost of communication (Malone, 2004). What users learn by using a product constantly feeds back to the firm via various channels — blogs, user communities, online forums, etc. — with relatively low cost and little effort. These feedbacks are much more detailed and sometimes filtered by the communities, creating important information that traditional marketing research cannot provide. Manufacturers and service providers learn what problems and issues occur during actual usage and use this information to update or improve the current product. Users nowadays have a much better idea of the inner workings of products and how manufacturers produce them due to frequent reverse engineering (often by hackers) and information sharing among users in various communities.

In this chapter, I focus on the exploration of an area somewhat neglected by management scholars — the space in which a manufacturer and diverse users interact and continuously learn from each other. While there is an increasing number of research studies on user innovation-based products and open source movement (von Hippel, 2005), I believe that management research should also focus on the interaction between manufacturers and users in order to understand how to internalize those innovative ideas and innovations that occur outside a firm's boundary. With the growing power of the distributed innovation of users and user communities, this focal space is interesting to scholars and practitioners alike. By understanding the nature of learning that involves those inside and outside the firm, and by tapping into the joint problem-solving practices

in this area, it is possible to understand and better manage the micro process of collaboration that can extend the learning-by-doing beyond the organizational boundary. Rather than seeing users as separate entities outside the firm's boundary, this paper views the users as valuable sources of knowledge that can be incorporated into the firm's learning process.

The rest of the chapter proceeds as follows. I first review the relevant literature and empirical studies to draw testable hypotheses on learning-by-interaction between a manufacturer and its users. Then using both qualitative and quantitative data, I explore the collaborative user-manufacturer problem-solving process in the product development stage. By examining 359 user-manufacturer co-development projects, I demonstrate that a focal manufacturer and its users show a learning curve identical to that observed within the boundary of a firm. But different from what the traditional learning-curve effect would suggest, I show that this learning-by-interacting with users benefits the *design* process rather than the *manufacturing* process. To understand the process of learning-by-interaction more deeply, I analyzed 2,365 communication logs with emails and phone call records and found that the timely and responsive feedback of interdependent information is critical in the continuous-design problem-solving in this user-manufacturer learning process. The effects of prior templating and distance on learning were also examined in the context of this field study. The results of the study are then reflected in current literature on dynamic capabilities and organizational learning to discuss the contribution of this work to those literatures. I conclude with a discussion of the direction for future research.

4.2. Theory and Hypotheses

4.2.1. Learning-by-Interaction: Learning Between Users and a Manufacturer

Learning has often been defined as a cumulative production experience (Arrow, 1962). Initial research on learning-by-doing focused on why the unit cost of production declines as production increases. Arrow (1962) argued that this is the result of the increase in production skills acquired by learning-by-doing. Most of the studies in this tradition focus on the relationship between the cumulative production experience and its impact on performance improvements such as cost, labor time, and error rate reduction (Argote, Beckman, & Epple, 1990; Argote & Epple, 1990; Gruber, 1994; Wright, 1936). The learning curve, also known as the experience curve, is the graphical and mathematical representation of the experience gained in production over time. The reason why the learning curve receives so much attention is because it can be used as a planning tool for future production. With the accurate estimation of the parameters of the rate of learning, a manufacturer can devise a production plan based on the expected rate of learning (Yelle, 1979).

Research on organizational learning has gradually shifted towards identifying the differences in the learning rates in various firms and the sources of these differences (Argote & Epple, 1990; Dutton & Thomas, 1984). Studies that focused on the actual process of learning-by-doing explain how field use of process equipment generates new knowledge (von Hippel & Tyre, 1995), and how engineering activity and training can be a second-order learning that influences the observed learning outcomes (Adler & Clark,

1991). These studies suggest that cumulative experience should not be treated as a "given". Rather, organizational learning should be viewed as a broad phenomenon that can occur in various loci of organizations with different implications for improvements in performance.

The practice of learning-before-doing suggests that learning can occur in various locations within the firm's boundaries (Lieberman, 1984; Pisano, 1996). Even before learning in a production facility starts, learning can occur through simulation, prototype building, and laboratory experiments, or by simply observing outcomes of similar processes. In learning-before-doing, the learning outcome is affected by the model's fidelity and the decision on the optimal switching point for different modes of experiments. This due to the fact that the high fidelity model can reveal a more detailed description of the real world, but is also more expensive to build (Thomke, 1998). The state of scientific and engineering knowledge also affects the learning outcome at this laboratory-oriented learning process (Pisano, 1996).

However, R&D laboratories and manufacturing/production floors are not the only places where learning takes place. It also occurs during the actual use of technology, which is specifically referred to as *learning-by-using* (Rosenberg, 1982). Not enough information on the problem-solving process is revealed during the production process, which leaves a lot of room for discovery and innovation. Habermeier (1990) argued that some user requirements and product characteristics are revealed only after customers use products for a long period of time. Users can find unique flaws in a product that can only be found in the actual physical settings of its use (von Hippel & Tyre, 1995). Traditional design theory posits that it is quite natural for users to devise novel product designs to

make improvements. Alexander (1964) stated that an artifact's design is a form that fits the context. As soon as it is created, it starts to interact with its embedded environment. This design specificity is often what manufacturing company designers focus on over the cost of the overall design. But this very specificity of a certain product also sheds light on ways diverse *users* and diverse *uses* can improve the same product in various environments. It is no surprise then that product users are more often the sources of functionally novel solutions compared to manufacturers who make merit improvements (von Hippel, 1988).

An area in which innovation scholars lack knowledge is how information revealed in the learning-by-doing process spills over to the learning-by-using process, and vice versa. The traditional view of the interaction between learning-by-doing and learning-by-using (i.e., the interaction between manufacturers and users), has been conceptualized as *uni-directional*. Manufacturers gather users' needs and develop products based on their input (Clark & Wheelwright, 1993; Ulrich & Eppinger, 2004). After gathering users' input, firms use their own mechanisms such as the "development funnel" or "stage-gate system" to process and evaluate ideas for new products (Clark & Wheelwright, 1993; Cooper, 1990). In this process, users' needs are conceptualized as crystallized elements that in turn become the production system's input. Suh (1990) stated that the need is actually formalized, resulting in a set of functional requirements. From this perspective, designers select the functional requirements and design the product. They then engage in design iterations to compare the product with the outlined functional requirements, and these iterations continue until a satisfactory fit emerges. This view is manufacturer-oriented in

that it leaves little room for thinking about learning-by-using and learning-by-interacting with users.

Another dominant view of the user-manufacturer interaction is that it is *iterative*. Von Hippel (1994) argued that the user's need and information about a solution should be brought together to the same location in order to solve design problems. But this type of information is often so "sticky" — costly to transfer from one location to another — that the problem-solving activities must iterate between the users and the manufacturer. From this view, users first draw on the local need information to specify the desired product or service. Then the manufacturer uses the local solution (capability) information to develop a prototype to meet the users' specifications. The prototype then is returned to the users so they can evaluate the product using the local need information. The iteration continues until the users are satisfied.

These perspectives do not necessarily assume that the users and the manufacturer can learn from each other over time. The uni-directional view assumes that it is possible to come up with a relatively complete set of requirements up front and that all the necessary effort to extract the requirements for a product design should be front-loaded. Therefore, learning-by-interaction with users doesn't mean much to manufacturers who hold this view; for them, product design and development based on functional requirements and continuous design improvements are more important. Even the iterative view provides some hints that learning can be hindered due to the "sticky" nature of information and the separate problem-solving that takes place in different loci of need and based on different solution information. But the iterative view also opens up the possibility of learning-by-interacting with users because they engage in the design iteration with the manufacturer

to a great extent. Manufacturers learn about users' specific needs and the specifications for products and services over time, while users learn about the manufacturer's capabilities; in this way learning-by-interaction is feasible.

Hypothesis 1 (H1): *A manufacturer and its users will learn by interacting with each other as the cumulative experience increases.*

Traditional learning theory studies that examine the effect of learning on production improvement often measure the direct labor hours per unit, cost reduction, and yield improvement. These studies focus on the learning effect on operational performance improvement. But the learning that results from the interaction between users and a manufacturer can also benefit the product design process. Manufacturers can secure valuable information about users' diverse needs and the various operational contexts in which the product could be used. Users, in return, learn from manufacturers about their manufacturing capability, which directly affects the design process since both parties will enhance each other's level of understanding on how to design new products or improve existing ones. But for this learning to influence the manufacturing stage and enhance the manufacturer's capabilities, the focal manufacturer has to make an extra effort to integrate the learning from various users over time. To more closely examine the learning-by-interaction effect, I will examine the effect of learning in two key stages of product development — design and manufacturing. Thus, the first hypothesis can be further specified that:

Hypothesis 1a (H1a): *A manufacturer and its product users will learn by interacting with each other as the cumulative experience increases; this learning will improve the design stage of new product development.*

Hypothesis 1b (H1b): *A manufacturer and its product users learn by interacting with each other as the cumulative experience increases; this learning will improve the manufacturing stage of new product development.*

4.3.2. Timeliness of Providing Interdependent Information

Designing a new product is a process of transforming an ill-structured problem into a well-structured problem (Anzai & Simon, 1979; Simon, 1973; Simon *et al.*, 1987). In this sense, the nature of problem-solving can be described as being progressive. At the initial stage, a certain part of the problem becomes increasingly structured. A well-structured part of the grand problem is repetitively used to solve the remaining ill-structured part of the problem. Since the ultimate goal of problem-solving is to find the route to the ultimate solution (Newell & Simon, 1972), finding and working on the well-structured area of the problem is very important to improve future problem-solving.

Problem-solving is also described as moving from the initial state to the goal state by finding a means that enables the transition (Newell & Simon, 1972). This progressive nature of problem-solving indicates that the prior state of the problem should be clearly defined and solved in order to move towards the later state. The trial-and-error process

described by Newell and Simon (1972) shows that when a certain trial fails, then the problem returns to the original state and problem-solver should follow another path to pursue a different, more successful outcome.

The progressive nature of problem-solving is also discussed in the engineering problem-solving context. Marples (1961) found that engineering design involves a series of decisions from the initial state of defining an abstract problem to the final state of specifying the hardware. New product development is a trial-and-error process in which alternative routes are identified after which the best possible route is selected (Allen, 1966; Brown & Eisenhardt, 1995; Clark & Fujimoto, 1991; Frischmuth & Allen, 1969; Thomke, 1998). Research and development departments as well as manufacturing departments engage in such problem-solving activities on a daily basis. For instance, as they learn more about a product or a process to develop a product or service, they get a clearer idea of the working mechanisms (Simon, 1973). This enhanced learning further informs the development process, thus increasing developers' depth of knowledge as they work towards a solution.

In the joint problem-solving approach, just like the learning-by-interaction between users and a manufacturer, this progressive nature of problem-solving becomes more complex due to the interdependence between users and a manufacturer. Design features are often interrelated to the manufacturing process (Griffin & Hauser, 1993; Hauser & Clausing, 1988). In that case, if a user moves from state A to state B of the design problem without the information about the interdependence from the manufacturer, then all the effort devoted to the problem-solving process to move from A to B might become useless. For example, if a user comes up with a design idea for a certain part of a product

and discovers later that the manufacturer cannot actually accommodate the design due to limited manufacturing capability, then all the effort that went into the design problem-solving will be for naught. Since designs change continuously, not all the interdependent information can be exchanged *ex ante*. Thus, the necessary information from the parties involved in joint problem-solving should be provided to enable the efficient step-by-step progress of problem-solving. Progress is possible without some necessary information, but it is not as efficient as having all of the key information since having the right information can reduce the amount of effort required in the trail-and-error process.

Task interdependence has long been used as the criteria for designing a more effective organization. By incorporating the concept of task interdependence, Thompson (1967) argued that the activities within an organization should be organized based on the degree of task interdependence: pooled, sequential, and reciprocal interdependency. This notion of task interdependence explains why and how the organization's boundaries are determined within the organization — i.e., among sub-units of the organization. For instance, when task interdependence is low, two sub-units can be disjoined while maintaining loose coupling with the supra-unit (pooled). If the output of one unit is the input for another unit, then the two units can be joined based on this input-output relationship (sequential). But if the task interdependence is very high and reciprocal, the two units should be considered for integration (reciprocal). This line of thinking, based on task interdependence, influenced many of the following perspectives on partitioning the organization.

Von Hippel (1990) emphasized the importance of task partitioning in innovation projects and argued that partitioning should be based on a certain criteria, such as the

reduction of information interdependence and cost in cross-boundary problem-solving. What matters in task partitioning is the actual information that has to travel between different parties involved in the joint problem-solving. As task interdependence increases, the amount of information, especially new information, that has to travel across the task boundary increases, thus rendering the project inefficient.

During the joint problem-solving process to design a new product, what also matters is the timeliness of the interdependent information. For example, let's assume that a home buyer (user) wants to build a new house and is making design changes A, B, and C. As the design changes, it also occurs in the interdependent information tied to the design changes that the user makes. If all three changes affect the average temperature of the house during the day, and if this is the user's primary concern, then the temperature change associated with the design changes A, B, and C should be provided to the home buyer immediately after each design change is made. Imagine if the information about the temperature is given after change B, but not after A. If the user does not like the information about the temperature after change B is made, then the user will have to go back to the previous design made before change A.

The responsive sharing of information between the user and the manufacturer is also important in learning-by-interaction. In the above example, the user will have a greater chance to learn about the association between a design change and how it will impact the temperature if the information is simultaneously provided with each change, thus decreasing the amount of information that has to travel between the two parties. But if the interdependent information is not provided in a timely manner, then the parties will suffer from their inability to associate the cause (design change) and the effect (the change in

the interdependent information). Problem-solving will also be negatively affected since the progressive result of this problem-solving will be rendered useless.

Here, I define unresponsiveness as *the failure to provide interdependent information in a timely manner*. By "timely," I mean that the interdependent information must be provided before any further design change is made. Due to the progressive characteristic of the design and the design process, it is important that the participating design collaborator provides relevant information at the time the design change is made. With the rationale provided above, unresponsiveness will negatively affect the design stage of a new product development project.

Hypothesis 2 (H2): *Failure to provide interdependent information in a timely manner (unresponsiveness) will negatively affect the design stage of a new product development.*

4.3.3. Templating

Templating, "a variant of trial-and-error" problem-solving (von Hippel & Tyre, 1995), refers to the pattern-matching process used to identify similarities and differences between patterns. Alexander (1964) stated that this type of problem-solving is a "common practice in engineering" in his discussion of the fit between form and context

(p. 19). Many engineering problems are not perfectly resolved during the product development and are discovered only later during the actual use in diverse contexts, which cannot be identified in the research and development phase or the manufacturer's production phase. By juxtaposing the product with the environment, new problems may emerge as the pattern matching progresses. In a more specific example, through the interferences between a process machine and its environment, new problems previously unidentified were found in the actual field use (von Hippel & Tyre, 1995). Eighty-one percent of the total problems (22 out of 27) were identified only after the process machine was used in the field environment.

Templating is quite an important part of the user-manufacturer joint problem-solving process. When users use a product in their work settings, they can identify problems and issues that were not visible in the manufacturing process. This is the type of information that a manufacturer can directly incorporate into the product development and manufacturing process to improve the product design and quality. Usually, this type of information feeds back to the manufacturer in the form of consumer complaints. User communities also share this type of information. But in the learning-by-interaction context, this templating process is done by the engineers in the manufacturing company and its users. Therefore, it is much more interactive and spontaneous.

Templating can affect the learning-by-interaction process between users and a manufacturer. Templating that takes place from a previous time period (t-1) helps problem-solving at time (t). Prior templating can identify engineering problems and can therefore subsequently assist the problem-solving in the upcoming projects. Since some parts of problems have already been resolved in most problem-solving settings — or at

least identified — those problems should not be issues in future projects. Thus, it is hypothesized that:

Hypothesis 3 (H3): *Prior templating until time (t-1) will be positively related to the learning outcome at time (t).*

4.3.4. Effects of Distance in Learning-by-Interaction

The question of how distance can affect the communication and collaboration outcome has been discussed in both management and information systems literature (Chidambaram & Jones, 1993; Cramton, 2001; Jarvenpaa & Leidner, 1998). An early study showed that the frequency of technical communication drops rapidly as the physical distance between co-workers increases. However, communication frequency asymptote to a certain level and does not drop any more as the distance approaches 30 meters (Allen, 1977). Surprisingly enough, many of the following studies do not capture the effect of varying degrees of distance: rather, they look at the dichotomous difference between complete collocation and complete dispersion (McGrath & Hollingshead, 1993; Van den Bulte & Moenart, 1998; Warkentin, Sayeed, & Hightower, 1997). The primary concern in these studies was *spatial distance,* which reduces the chance of face-to-face contact. The assumption is that having less face-to-face contact reduces the chance of effective communication and collaboration, reducing the ability to resolve complicated technical issues. Empirical studies have mainly used discrete distances such as same

floor/building/city (Cummings, 2004; Finholt & Sproull, 1990) and collocated/virtual/global teams (McDonough, Kahn, & Barczak, 2001) under the assumption that after team players are separated by a certain distance, different degrees of distance will make no difference. In other words, once team members are separated, for instance, by 100 miles, it makes no difference whether they work in the same state or province or on the other side of the globe.

Another important dimension of distance is temporal distance. Once two parties are separated by a certain distance, spatial distance does not affect the opportunity for face-to-face meetings. But if the physical distance between the two parties grows, they have a greater chance of using various communication technologies. Temporal distance tends to reduce the chance for synchronous interaction due to time difference, thus it is known to reduce real-time joint problem-solving (Grinter, Herbsleb, & Perry, 1999; Herbsleb, Mockus, Finholt, & Grinter, 2000; Malone & Crowston, 1994). More detailed and composite measures for dispersion were developed by O'Leary and Cummings (2007). They included spatial, temporal, and team configurational measures (e.g. isolation and imbalance) to characterize the geographic dispersion. These three factors should be considered for those user-manufacturer interactions that involve more than one person from each side. But if there is only one person from each side, configurational factors do not need to be considered. In my study setting, the latter was the case for deciding which factor should be considered for examining the effect of distance on learning.

User-manufacturer learning is not free from these effects. When the manufacturer and the users are not located on the same site, this spatial distance affects their chances of having face-to-face contact. But more importantly, temporal distance affects problem-

solving more directly since the manufacturer and the users will have less of an opportunity to have synchronous communication. The problem-solving should depend more on asynchronous communication, such as email, and this affects the efficiency of the joint problem-solving.

Hypothesis 4 (H4): *Spatial and temporal distance are negatively associated with the learning outcome.*

4.3. Empirical Analysis

4.3.1. Research Setting

This field study was conducted in a Canadian manufacturing company, Protocase, Inc. which specializes in low-volume production of custom-made electrical component enclosures — boxes that house components such as printed circuit boards and connectors. This manufacturer's main customers include a range of research labs and new product development teams at large companies and research organizations that require enclosures for prototyping. These customers include Boeing, IBM, NASA (three divisions), UCLA, Stanford University and MIT among many others. Protocase, which initiated production in 2002, has custom product development projects in more than 40 U.S. states and every Canadian province.

The focal manufacturer presents a compelling case for this study since the firm engages in highly interactive joint problem-solving processes with its customers. From new product design to product delivery, the manufacturer and its users engage in joint problem-solving to develop product designs that meet customers' unique requirements. Even though users (customers) and manufacturers typically engage in various forms of communication and collaboration, this setting provided me with more directly observable situations via custom product design process, which in turn enabled me to understand the inner workings of a user-manufacturer joint problem-solving process. I was also able to observe the effects of cumulative experiences in joint product development projects since

many customers returned to the manufacturer for different projects and deepened their collaboration, knowledge-sharing, and expertise.

4.3.2. Data Collection

Data was gathered from three sources: 1) interviews with managers and employees in the manufacturing company, 2) communication logs of the emails and phone calls exchanged with users, and 3) the manufacturer's project data stored in the information systems. I conducted a total of seven interviews with the CEO, Research Director, Software Developer, Technical Support, Marketing/E-commerce, and two Sales Engineers and asked open-ended questions to understand how interaction with users in general occurs. Each interview lasted from 60 to 90 minutes (the average was 72 minutes). The interviews were tape recorded during the session and transcribed later for analysis. The interview protocol was semi-structured in that there were some pre-set questions, but most questions were open-ended due to the interviewees' various job specifications and perspectives.

Emails were logged with full details of the messages including the text itself, and phone calls were logged with the summary of the conversation. The manufacturing company had a policy of recording all the emails (incoming and outgoing) in the company database. Phone calls were recorded as well but not as strictly as emails. A total of 2,365 email and phone calls were logged between March 2005 and March 2006. Of these 2,365 logs, 97% were emails and only 3% were phone calls. All communication data was anonymized in order to protect the identity of the employees and the users.

Project data was gathered from the company's two separate databases: the customer relationship management (CRM) system data, and the order management system (OMS) data. From these two databases, data on 359 user-manufacturer co-development projects within the firm under study were collected and combined with the communication data. For each project, one engineer from the user's (customer's) side and one engineer from the manufacturer's side carried out most of the communications. Even though other engineers from both sides indirectly participated in the project and their input appeared in the conversations between these "representative" engineers, almost all of the communication and interaction took place between these two engineers. These representative engineers were very similar to the gatekeepers in Allen's work (1977) in that they were the ones who engaged in the joint problem-solving and the interpretation of communication from each other's side.

Combining the communication records and project data, I gathered a fairly complete set of information on email and phone call communications for all 359 projects. It was the manufacturing company's regular work protocol to record emails during the early stage of data collection; the person in charge of database management mentioned that the company recorded approximately 80% of the emails exchanged with users in the database. Emails were recorded directly from the email client program, therefore included all the contents. Phone calls were summarized and recorded in the database much less frequently. The resulting communication data and project data allowed me to examine the nature of the communication between the users and the manufacturer during the joint design problem-solving process as well as the effect of the cumulative experience of the users-manufacturer interaction.

4.3.3. Data Analysis

My analysis of the interview data guided me to focus on several research questions and hypotheses about joint problem-solving between users and a manufacturer. This is a major strength of a field study: the theory and hypotheses testing is not only based on existing theories and empirical data, but also on the rich empirical setting, which encourages inductive reasoning (Edmondson & Mcmanus, 2007; Glaser & Strauss, 1967).

I analyzed the data in two different stages. During the first stage, communication logs were analyzed following the instructions on the coding procedure for the qualitative data described in various sources (e.g. Golden-Biddle & Locke, 1997; Miles, 1979; Strauss, 1987). The main categories were identified, and more detailed sub-categories were developed through iterative analysis of the contents of all of the emails. All communication content was categorized to provide a relatively complete picture of what was communicated between users and the manufacturer during the co-development efforts. I started with the open coding described in Strauss (1987) to identify the main categories, then moved on to axial and selective coding to select the sub-categories. Three iterations were carried out until the coding scheme stabilized. The resulting coding scheme and number of messages in each category is shown in Table 4.1.

After the content analysis (stage one) was completed, I carried out the second-stage data analysis, which combined the results from the communication and project data. At this stage, I developed formal hypotheses and designed two separate learning models to test these hypotheses.

Table 4.1. Different Types of Messages between Users and a Manufacturer (N=2365 messages)

Category	Details	Number of Messages
Design Related		
Design Information	Exchange of design related information	632
Official Project Initiation	Project initiation by receiving formal orders with design specifications	242
Templating	Problem-solving after delivery of the product	84
Feedback Seeking	Feedback seeking after the product delivery	138
Positive Feedback	Users expressing their level of satisfaction on the product delivered	95
Clarification	Clarification of concepts and terms	15
Price Related		
Price Information	Price related information	336
Shipping Related		
Shipping Information	Shipping inquiry & confirmation	381
Production Related		
Production Related Q & A	Lead time, manufacturing process related information	36
Marketing/Sales Related		
Follow-up Contacts	Follow-up messages for sales purposes, marketing communication	141
Others		
Miscellaneous Information	Greetings, payment, contact information	265

4.3.4. Statistical Models and Variables

4.3.4.1. Learning Models

Various methods have been used to measure the effects of learning but traditional measures of learning such as cost, productivity, and quality, only capture the learning effect of the manufacturer. To measure the effect of learning-by-interaction, the total design time used to design the product is used as the dependent measure. Design time is a valid measure in this case because it captures the effect of learning between the users and the manufacturer through their cumulative experience in designing the product together. A time-related measure has been used in other studies since time-to-market has become a very important issue in innovation studies due to the fast changing environment (e.g. Eisenhardt & Tabrizi, 1995).

In order to examine the learning-by-interaction effect on the manufacturer's side, I examined a similar model with the lead time as the dependent variable. Lead time is a more traditional measure of learning that can show the learning effect on the improvement in manufacturing performance. With separate models for design time and lead time, the effect of learning on design-oriented tasks and manufacturing-oriented tasks were separately examined.

I specified the following two models to examine the five hypotheses presented (H1a, H1b, H2, H3, and H4).

Design-Time Learning Model:

$$\ln(\textit{Design Time}_i) = \alpha_0 + \beta_0 \textit{Complexity}_i + \beta_1 \textit{Size}_i + \beta_2 \ln(\textit{Experience}_{ij}) + \beta_3 \textit{Unresponsiveness}_i + \beta_4 \textit{Prior Templating}_{ij} + \beta_5 \textit{Spatial Distance}_j + \beta_6 \textit{Temporal Distance}_j + \beta_{7j} \textit{User Company}_j + e_{ij}$$

Lead-Time Learning Model:

$$\ln(\textit{Lead Time}_i) = \alpha_0 + \beta_0 \textit{Complexity}_i + \beta_1 \textit{Size}_i + \beta_2 \ln(\textit{Experience}_{ij}) + \beta_3 \textit{Unresponsiveness}_i + \beta_4 \textit{Prior Templating}_{ij} + \beta_5 \textit{Spatial Distance}_j + \beta_6 \textit{Temporal Distance}_j + \beta_{7j} \textit{User Company}_j + e_{ij}$$

4.3.4.2. Dependent Variables

Two dependent variables are used in the models.

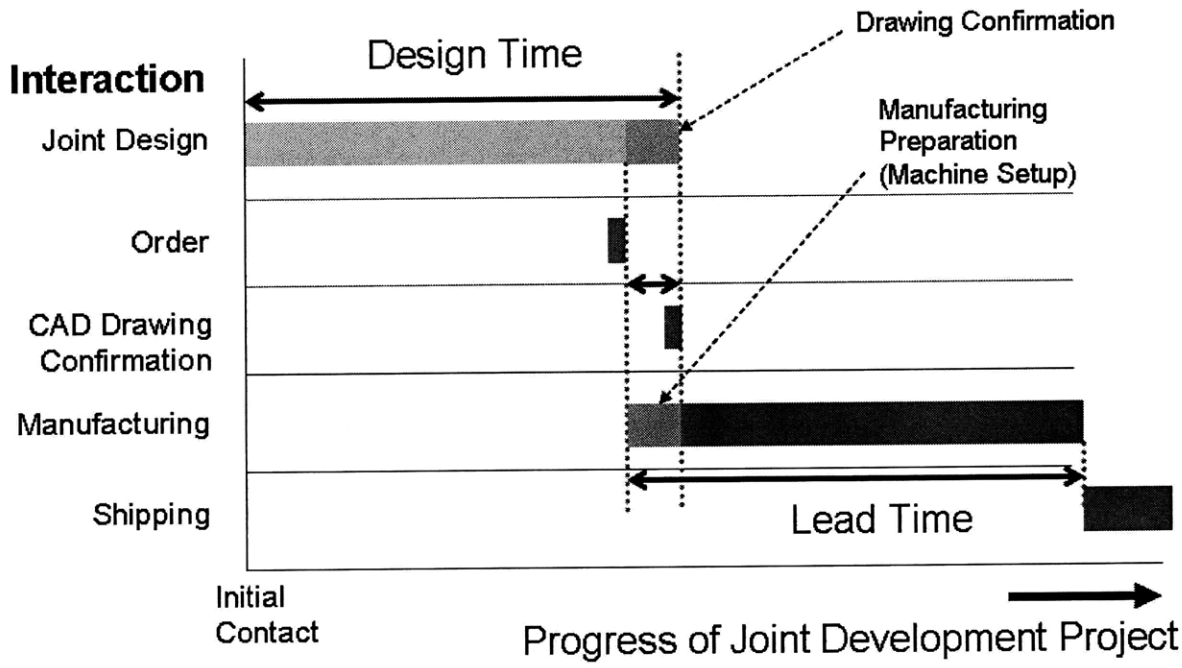
$\textit{Design Time}_i$ is the time it takes to design a product for project *i* measured in days. The starting date (day one) for design time is the day that the users and the manufacturer initiate communication to design a product, and the ending date is the day that the manufacturer approves the engineering drawing to manufacture the product.

$\textit{Lead Time}_i$ is the time from when the project$_i$ officially starts; it begins on the day that the manufacturer formally processes the design product order until the product is

shipped from the manufacturer. The lead time duration includes 1) the time that it takes the manufacturer to complete the final CAD drawing of the product and get final approval from the user, and 2) the time it takes to manufacture the product. Manufacturing begins as soon as the final drawing is approved by the user.

The design time between the official start of the project and final drawing approval is included in both $Design\ Time_i$ and $Lead\ Time_i$, therefore there is a slight overlap between these two measures (Figure 4.1). The overlapped area was deliberately included in both measures. Since drawing approval is an important part of designing a product, it should be included in the design time measure. But at the same time, the drawing for the final approval is a manufacturer-centered activity. Therefore, $Design\ Time_i$ represents the joint manufacturer-user design process, and $Lead\ Time_i$ represents the manufacturing process.

Figure 4.1 Dependent Variables – Design and Lead Time



4.3.4.3. Control Variables

Each project varies in terms of design complexity and magnitude. In order to control the size and complexity effects, two control variables were used, $Complexity_i$ and $Size_i$.

$Complexity_i$ is measured by the unit price of the product designed for project *i*. The product's unit price is measured by the manufacturer's pricing scheme based on the physical properties and process parameters. As the number of product features and the difficulty of manufacturing increases, the product's unit price increases correspondingly. Product complexity can affect the design and manufacturing time in a significant way, therefore it should be controlled in the learning models.

$Size_i$ is measured by the quantity of the product ordered for project *i*. A project producing a product to be manufactured in high quantities can require more attention and time to design and produce. Therefore, the quantity of the product ordered for each project was used to control the effects from projects of various magnitudes.

4.3.4.4. Independent Variables

Five independent variables were measured in order to test the hypotheses one through four.

$Experience_{ij}$ represents the number of projects a manufacturer completes with user *j* prior to project *i*.

$Unresponsiveness_{i}$ is represented by the number of design changes that do not correlated to changes in pricing information in project *i*. Here is a more detailed explanation of this independent variable. Price changes as the user changes product features (e.g., material type, material thickness, finish, number of cutouts, number of self-clinching fasteners, enclosure type, number of silk screen colors and faces screened). At the same time, the price also relates to changes in the process parameter (e.g., the time required for material cutting, grinding/ finishing, welding, bending, fastener insertion, painting, silk screening, assembly, and packaging). Therefore, the manufacturer must provide its customers/users with price information (interdependent information) each time the user changes product properties. The total number of design changes that take place without the pricing information that the manufacturer could provide is used as the measure for manufacturer unresponsiveness in a given project. All the messages exchanged during the project were sequentially ordered to measure the timeliness of the interdependent information that each partner provided the other. In this field study setting, pricing information was used as the interdependent information, which changes as the design changes.

Prior Templating$_{ij}$ is the number of templating-related messages (phone or email) exchanged between manufacturer and user *j* prior to project *i*.

Spatial Distance$_j$ is the physical distance from the manufacturer to user *j* measured in miles.

Temporal Distance$_j$ is the time zone difference between the manufacturer and user *j*.

User Company$_j$ is the vector of user company dummy variables that are used to assess whether there is any difference in initial state of learning among different users.

The two learning models presented are estimated with the Ordinary Least Square (OLS) regression. The log specification of the dependent variables and experience-related independent variable follows the convention of previous studies on the learning curve (Argote, 1999). Log specification is based on the fact that the design time or lead time cannot be reduced infinitely. As the design time and lead time decline due to the learning effect, an incremental reduction is more difficult to achieve over time.

The learning model, β_2, captures the learning effect of cumulative joint problem-solving projects on the design and lead time across all users. If there is a learning effect, then this coefficient should have a negative sign indicating that as cumulative experience increases, it takes less time to design the product. β_3 captures the effect of unresponsiveness to the design and lead time. If this coefficient is positive, then, as the number of no-responses-to design changes increase, the design time correspondingly increases. β_4 represents the effect of the differing amounts of templating experience on design and lead time. β_5 and β_6 captures the effect of spatial and temporal differences on design and lead time. β_{7j} is a vector of coefficients that captures the initial difference

of design and lead time from an unobserved user effects. For example, if the user is a mechanical engineer, then it should be easier for him or her to have a shorter design time than a chemical engineer.

4.3.4.5 Different Experience Measures – Learning at the User Boundary

To capture the learning effect between a manufacturer and its users, I use the following measurement.

- $Experience_{ij}$: The number of projects a manufacturer completes with user j prior to project i.

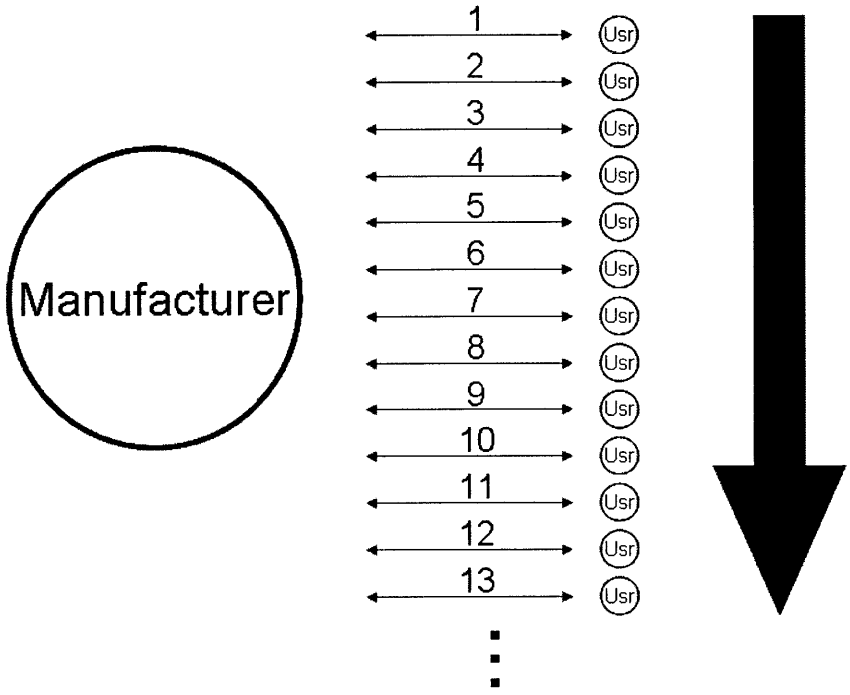
I use two other variables that capture the cumulative experience. By comparing the effect of these two other variables, I try to distinguish the merit of this study against the measures that traditional learning studies have focused on.

- *Cumulative Products i* : Number of products produced until project *i*
- *Mfr Experience i* : Number of projects the manufacturer completed prior to project *i*

Traditional learning studies have used cumulative experience as measured by cumulative production outputs. While these studies measure the cumulative experience of

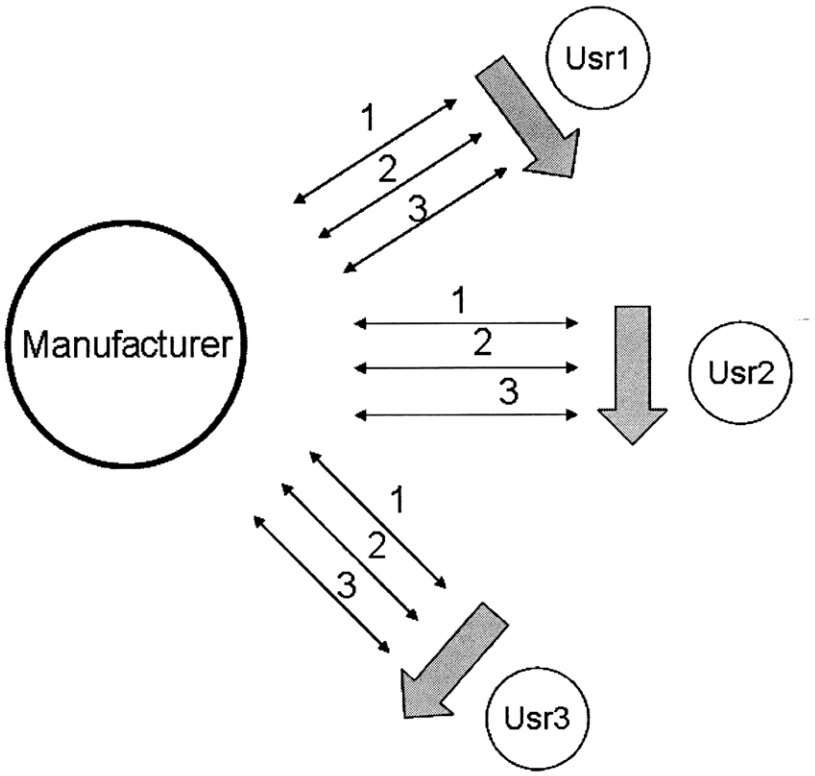
the manufacturer, they do not distinguish between the different experiences derived from different users. In these studies, the focus of the experience is on the production floor. Therefore, different and unique experiences that can be acquired by interacting with different users are not captured in these studies (Figure 4.2.).

Figure 4.2. Learning from the Manufacturer's Perspective – Traditional way of measuring learning



On the contrary, the current study captures the cumulative experience between a manufacturer and its users and the effect on the outcome measure – in this case, the lead time and the design time during the product development process (Figure 4.3). By using this measure of experience that captures the cumulative experience with a specific user, I can show the learning effect at the user boundary of the firm.

Figure 4.3. Learning at the User Boundary



The rationale for using this measure is the following. There is a unique and valuable experience with each user that can be attributed to the improvement made in the outcome. Manufacturers learn how specific users want specific products. They also learn over time about users' specific product usage environments. These learning effects can guide the manufacturer to come up with a better product and product development process for specific users.

Users also learn over time the specific capabilities of the manufacturer. There are technical elements that the manufacturer can and cannot deliver over a certain period of

time. By learning about which technical elements the manufacturer can deliver, users are better equipped over time to cope with the focal manufacturer. Users also learn the manufacturer's way of solving problems. They become aware of the manufacturer's problem-solving language and understand it better over time.

Traditional ways of measuring learning did not pay attention to the user boundary and what happens with the cumulative experience that takes place with users. In the following section, I will discuss the findings from using these three different measures of capturing learning in the same model. It will give the readers a chance to look at the value of measuring learning at the user-manufacturer level.

4.4. Findings

Table 4.2 shows the result of the Ordinary Least Square Regression on Design Time. In model 1, I used the cumulative experience between the focal manufacturer and its users $Experience_{ij}$. This is the way I measured the cumulative experience in the following models to test the hypotheses, the same way this study captures the learning effect throughout this dissertation. In model 2, I used the cumulative number of products the manufacturer produced during the period captured in the data set. This is analogous to the traditional ways of capturing the learning effect. In model 3, I used the cumulative number of projects from the manufacturer's point of view regardless of which specific user the manufacturer worked with. This way of capturing the learning effect is somewhat similar to model 1 – but it differs in that model 3 uses the cumulative number of projects rather than the cumulative number of products produced. In other words, this model captures the experience of working in other projects with a user. Model 4 captures the learning effect from working with a specific user and how it changes as the learning experience increases.

In model 1, the learning effect captured at the user-manufacturer level holds. The same effect is found to be significant in model 4 when it is controlled for the manufacturer's experience. In model 3, the manufacturer's additional project experience is found to be significant (at $p<0.1$). However, this effect is gone in model 4, which shows that the user-manufacturer experience ($Experience_{ij}$) is the important explanatory variable for the change in the outcome level (*Design Time*).

Table 4.2 Ordinary Least Square (OLS) Regression on Design Time

Dependent Variable: ln(Design Time) **(N=359 projects)**

	Models			
Variables	1	2	3	4
Constant	2.195***	1.905***	2.211***	2.397***
	(0.10)	(0.35)	(0.29)	(0.27)
Control Variables				
Complexity	0.001*	0.001***	0.001***	0.0005*
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Size	- 0.001	- 0.001	- 0.001	- 0.001
	(0.002)	(0.002)	(0.003)	(0.002)
Independent Variables				
ln*(Cumulative Products)*		- 0.027		
		(0.048)		
ln*(Mfr_Experience)*			-0.101+	- 0.042
			(0.056)	(0.053)
ln*(Experience)*	- 0.355***			- 0.348***
	(0.049)			(0.050)
F	23.99	6.00	7.00	18.13
R-sqr	0.169	0.048	0.056	0.170
Adj R-sqr	0.162	0.040	0.048	0.160

Standard Errors are shown in the parentheses
*+p<0.1, *p<0.05, **p<0.01, ***p<0.001*

Table 4.1 shows the coding scheme results from the content analysis. Of the total messages, 51% were design related while 16% were shipping related and 14% were price related. These three categories turned out to require a high degree of user-manufacturer communication during the joint-product development. Figure 4.4 shows the volume of communication during each of the four stages of the project. Much communication occurred even before the official start of the project when users formally submitted the purchasing order. Design (43%) and pricing information (27%) exchanges constitute the major part (70%) of communication in this early stage (Figure 4.5 and 4.6).

After the purchasing order is submitted, the design process involves the refinement of the product design and final approval of the CAD drawing. This entails not only devising the best design, but also finding an agreement on a design. Both the user and the manufacturer must agree on a certain design before it moves to the manufacturing stage. The approved CAD drawing is not only used to represent the final design parameters, which help the communication between the two parties, but the drawing also serves as a part of the binding contract between both parties.

As the project moves to the manufacturing stage, communication in both design and pricing information drops (it only averages 0.46 messages per project in this stage), and shipping information exchanges take over to represent 51% of the communication events (Figure 4.6). However, the overall volume of communication drops at this stage since once the manufacturing begins, the design solution has already been chosen and therefore, less communication is needed between the two partners.

After the product is shipped, shipping inquiries increase and represent 37% of the communication volume. A noteworthy observation is that different types of problem-solving, such as templating and feedback exchanges, come to dominate 51% of the communication events.

Figure 4.4. Communication Frequency by Project Stages (N=2365 messages)

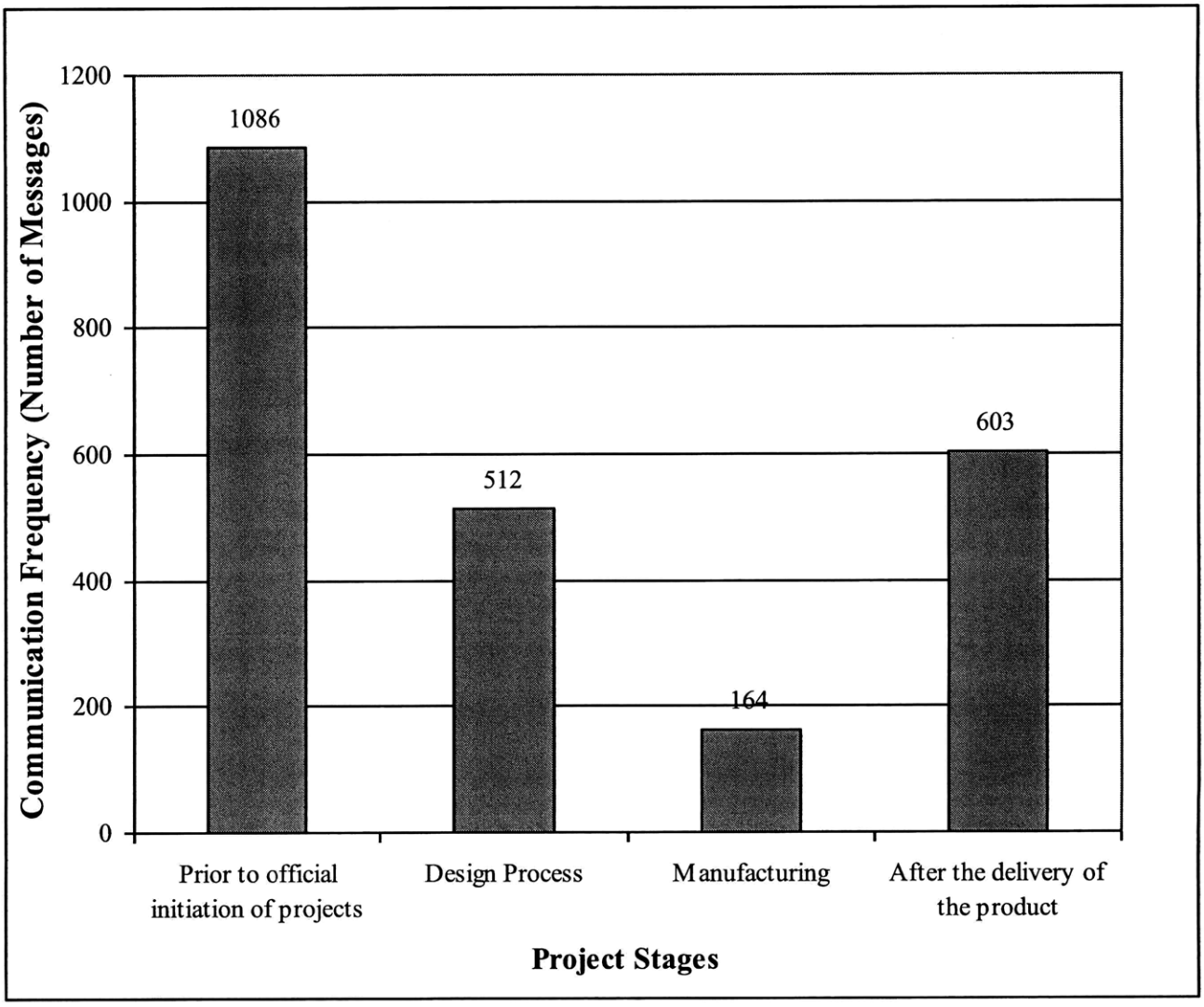


Figure 4.5. Volume of Each Type of Messages in Four Project Stages (N=2365 messages)

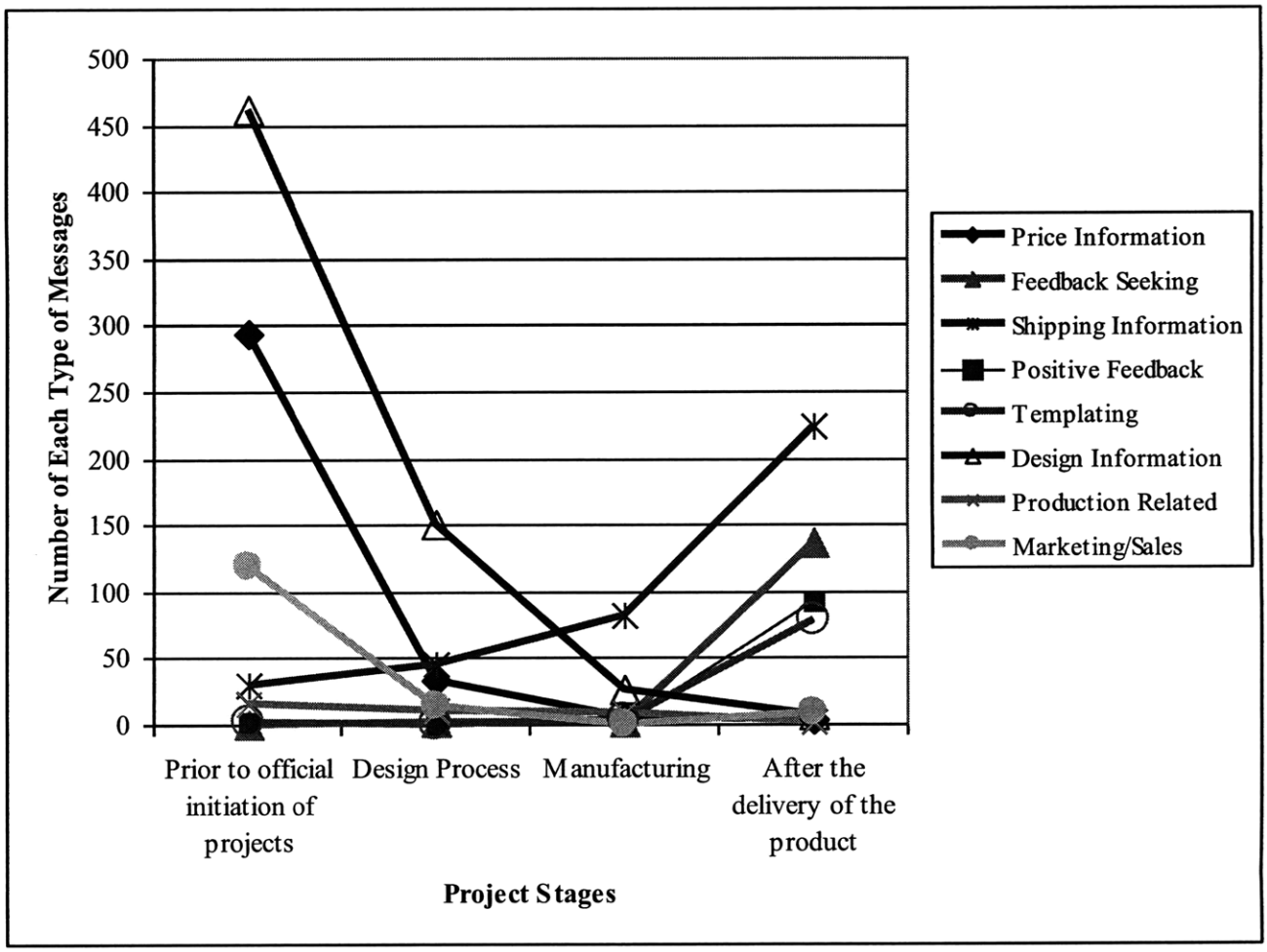


Figure 4.6. Proportion of Each Type of Message in Different Project Stages (N=2365 messages)

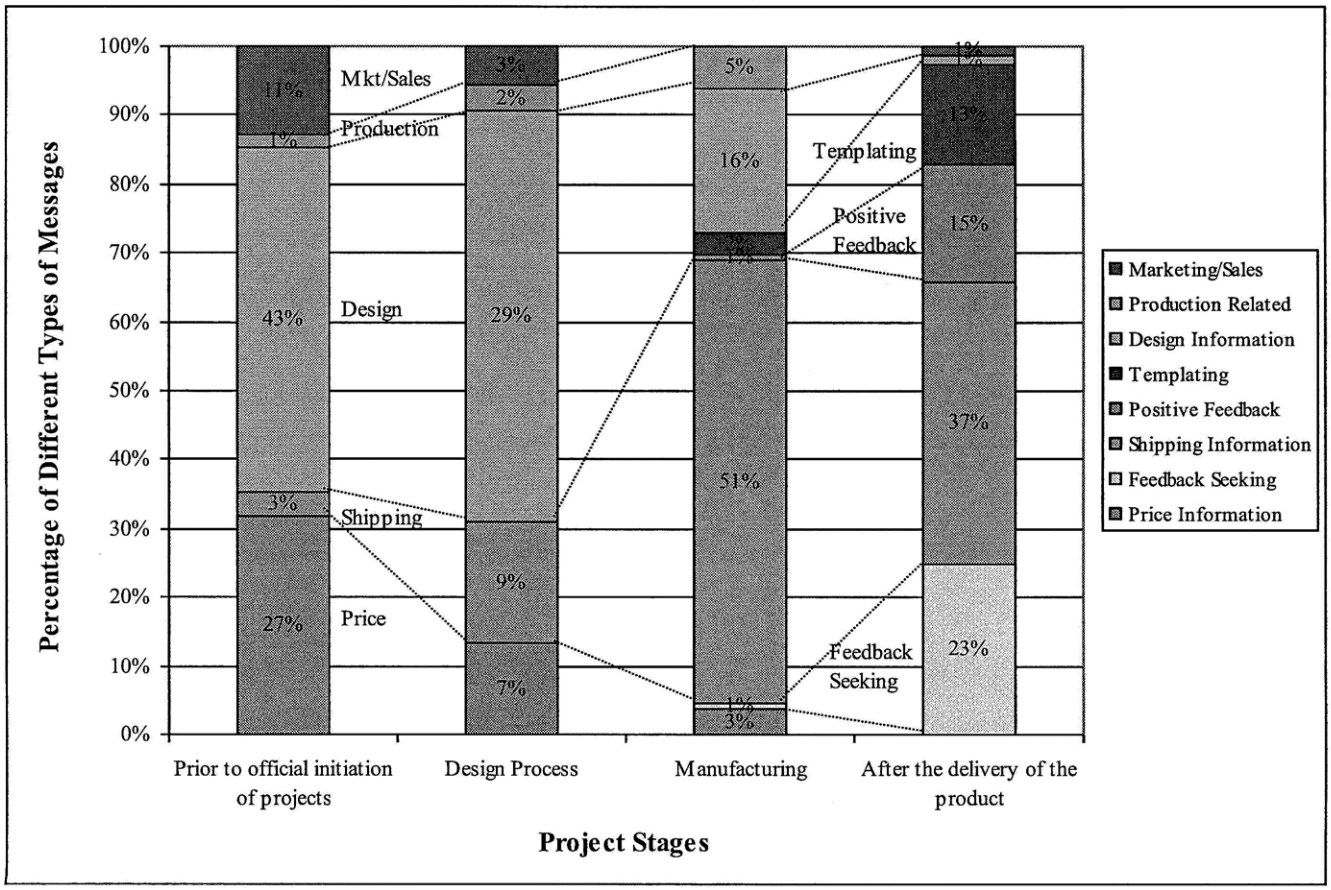


Table 4.2 shows the descriptive statistics. Tables 4.3 and 4.4 show the results of an OLS regression on the design time and lead time respectively. The most significant finding is that the learning effect is only visible in the design-time model, but not in the lead-time model. Only β_2 in the design-time model (Table 4.4) is statistically significant ($p < 0.001$) and shows the negative sign I expected from Hypothesis 1a (H1a). This means that learning-by-interaction took place between the users and the manufacturer at the design stage of this co-development project. Since the products designed are customized products for each customer (user), the learning effect of the two parties having worked on a greater number of products may not lead to an improvement in the manufacturing stage due to the unique characteristics of each product. Since β_2 captures the improvement in lead time with respect to the increased experience of the manufacturer and a specific user, the improvement in the manufacturing stage (lead time) may not be significant enough to be shown in the regression result. The manufacturing technology in this field site was quite standardized across all projects in order to produce customized products quickly. Therefore, the user-specific learning effect may not have led to improvements in manufacturing technology. I need to do further analyses to decide whether there was an overall learning effect across all customers. Since the experience measured here is bounded by each user, the overall cumulative experience across all users could affect the manufacturing efficiency.

Table 4.3. Descriptive Statistics and Correlation Matrix

	Variable	Mean	S.D.	1	2	3	4	5	6	7	8
1	ln(*Design Time*)	1.90	1.06	1.000							
2	ln(*Lead Time*)	1.75	0.80	0.431	1.000						
3	ln(*Experience*)	1.14	1.08	-0.394	-0.161	1.000					
4	*Complexity*	231.53	251.33	0.214	0.283	-0.266	1.000				
5	*Size*	8.26	22.46	-0.076	0.145	0.123	-0.173	1.000			
6	*Unresponsiveness*	1.45	2.27	0.406	0.221	-0.245	0.117	-0.011	1.000		
7	*Prior Templating*	0.14	0.34	-0.180	-0.046	0.287	-0.105	0.023	-0.118	1.000	
8	*Distance*	1765.46	1020.86	-0.058	0.021	0.022	-0.051	0.031	-0.084	0.233	1.000

Table 4.4. Ordinary Least Square (OLS) Regression on Design Time (N=359 projects)

Dependent Variable: ln(Design Time)

	Models				
Variables	1	2	3	4	5
Constant	2.195***	2.279***	1.914***	1.917***	1.982***
	(0.10)	(0.29)	(0.13)	(0.10)	(0.22)
Control Variables					
Complexity	0.001*	0.001+	0.001*	0.001*	0.001+
	(0.0002)	(0.0004)	(0.0002)	(0.0002)	(0.0002)
Size	- 0.001	- 0.006	- 0.001	- 0.001	- 0.001
	(0.002)	(0.004)	(0.003)	(0.002)	(0.002)
Independent Variables					
ln(*Experience*)	- 0.355***	- 0.442**	- 0.281***	- 0.274***	- 0.277***
	(0.049)	(0.143)	(0.064)		(0.070)
Unresponsiveness			0.151***	0.151***	0.150***
			(0.022)	(0.022)	(0.022)
Prior Templating				- 0.029	- 0.015
				(0.052)	(0.053)
Spatial Distance					- 0.0002
					(0.0001)
Temporal Distance					0.131
					(0.103)
User Company Dummies		*			
F	23.99	6.01	32.21	25.78	18.64
R^2	0.169	0.714	0.267	0.268	0.271
Adj-R^2	0.162	0.322	0.258	0.257	0.256
N	359	359	359	359	359

Standard Errors are shown in the parentheses

*+p<0.1, *p<0.05, **p<0.01, ***p<0.001*

Table 4.5 Ordinary Least Square (OLS) Regression on Lead Time (N=359 projects)

Dependent Variable: ln(Lead Time)

	Models				
Variables	1	2	3	4	5
Constant	1.567***	1.570***	1.454***	1.450***	1.446***
	(0.13)	(0.17)	(0.083)	(0.14)	(0.11)
Control Variables					
Complexity	0.001***	0.001**	0.001***	0.001***	0.001***
	(0.0002)	(0.0004)	(0.0002)	(0.0002)	(0.0001)
Size	0.007***	0.013***	0.007***	0.007***	0.007***
	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)
Independent Variables					
ln(*Experience*)	- 0.080*	- 0.154	- 0.051	- 0.060	- 0.063
	(0.038)	(0.113)	(0.038)	(0.040)	(0.040)
Unresponsiveness			0.060**	0.062**	0.061**
			(0.018)	(0.018)	(0.018)
Prior Templating				0.025	0.043
				(0.040)	(0.043)
Spatial Distance					- 0.0002+
					(0.0001)
Temporal Distance					0.175*
					(0.083)
User Company Dummies		*			
F	17.63	8.40	16.59	13.40	10.40
R^2	0.130	0.677	0.158	0.160	0.172
Adj-R^2	0.122	0.235	0.148	0.148	0.155
N	359	359	359	359	359

Standard Errors are shown in the parentheses

*+p<0.1, *p<0.05, **p<0.01, ***p<0.001*

In terms of the user company's dummy variables, I only indicate whether the vector is statistically significant. The result of the F test shows that the size of the user-specific effects on both the design time ($F = 1.413, p < 0.05$) and the lead time ($F = 1.257, p < 0.1$) varied significantly across the different users. But this effect was only on the initial design time and lead time. To examine the difference in learning-curve rates, the interaction effect between the cumulative experience and the user company's dummy variables need to be examined. Unfortunately, the sample size was not large enough to examine the interaction effect. But the initial design and lead time difference indicates that the manufacturer needs to better manage the learning-by-interaction process and pay attention to the individual users who show high initial design and lead time in order to enhance the company's learning curve.

The implication of the design-time improvement is quite important. The fact that learning-by-interaction with users had a positive impact on the design stage (measured by the negative coefficient β_2 in design time model) means that considerable learning can indeed occur between users and a manufacturer on the product design improvement. Thus, manufacturers can expect a reduction in the time-to-market corresponding to the cumulative experience with the same user. The fact that learning can occur from interaction and/or joint projects with organizations outside of the firm boundary means that firms can expect to benefit from focusing their efforts on building relationships with users.

I also found that as unresponsiveness increased, both the design time and the lead time increased ($\beta_3 = 0.150, p < 0.001$ in design time model 5, $\beta_3 = 0.061, p < 0.01$ in lead time model 5). This means that if the manufacturer does not respond to the design

changes with relevant feedback properly, the joint problem-solving process will take more time to complete. The coefficient β_3 is much larger in the design time model, which suggests that manufacturers should pay more attention to the design stage and quickly respond to design changes from the users with the relevant information during the this stage.

The effect of prior templating (β_4) was not significant in both models. In order for templating to decrease the design and lead time to a significant degree, the issues raised in the prior templating should be the relevant issue during the subsequent projects. This was not true in this field study setting since each product design was quite unique, and different design issues could have come up in each project. Similar to the effect of the experience on the lead time, I need to examine a larger set of data over longer periods of time to more extensively examine the effect of templating. This may include product features or innovative ideas that do not specifically relate to reducing the design time. Larger sets of data that include a longer period of the templating process may shed more light on this matter.

The most difficult result to interpret is the effect of distance. Both spatial and temporal distance did not affect the design time significantly whereas temporal distance affected the lead time negatively ($\beta_6 = 0.175, p < 0.05$). During the design stage, any issues that came up may have been resolved through asynchronous communication technology. But for the issues that came up during the manufacturing stage, there should have been a greater urgency to resolve the issue since manufacturing was already in progress. In this case, the need for synchronous communication increased, thereby, the temporal distance had an impact on the manufacturing stage. Another possible

explanation regarding the effect of temporal distance on lead time ($\beta_6 = 0.175, p < 0.05$) is that many users asked about shipping and shipping expedition (51% of total communication events during the manufacturing stage), and this may have turned out to be salient in the result because, as observed in the email conversation, there was a user tendency to make phone calls to expedite the shipping process. A synchronous communication medium such as a phone call is susceptible to time zone differences since it is more difficult to make urgent phone calls with people in different time zone. What is important is that the distance (both spatial and temporal) did not have an impact on the design time. This finding suggests that learning-by-interaction is possible regardless of the distance between the partners. But this proposition should be carefully tested using a larger dataset.

4.5. Discussion

In this paper, I proposed two different learning models that explain the learning-by-interaction that takes place between a manufacturer and its users. In my field study, I found that the joint problem-solving between a manufacturer and its users leads to an increasingly shorter design time as experience accumulates, proving the learning-by-interaction can indeed occur outside the manufacturer's boundary, particularly in user-manufacturer projects. This paper's main finding on learning-by-interacting with users is deliberately positioned in the learning-by-doing and learning-before-doing literature in order to emphasize that learning-by-interaction can occur at the boundary of the firm at the user-manufacturer boundary and that it can positively impact the product design.

From a broader perspective, this study of a manufacturer's learning-by-interaction with users contributes to the learning literature by combining two different views on organizational learning. While the *interaction* part emphasizes interactive and ongoing joint problem-solving, *learning*, as the outcome of the interaction, shows the cumulative nature of learning. Learning in organizations has been studied from two perspectives: as a *process* and as an *outcome* (Edmondson, 1999; Levitt & March, 1988). The process school of thought emphasizes the process of learning, which is ongoing, interactive, and sensemaking (Argyris & Schön, 1978). This school emphasizes learning as an error-detection process and as a practice, challenges the fundamental norms and values of organizations. The latter emphasizes the outcome of learning by focusing on routine-based, history-dependent, and target-oriented learning (Levitt & March, 1988). Outcome-based learning encodes inferences from past experience and incorporates it into routines.

Routines also affect future learning by guiding organization's search behavior. Learning-by-interaction with users observed in this paper indicates that a firm that engages in highly interactive learning with its customers/users can accumulate knowledge, which is shown by the learning curve presented in this paper.

Another interesting aspect of learning-by-interaction described in my work is that it leads to capabilities that are routine, stable, complex, path-dependent and hard-to-duplicate as described in the traditional literature (Barney, 1991; Nelson, 2000; Peteraf, 1993; Wernerfelt, 1984). The routine and path-dependent nature of capabilities comes from the fact that a firm needs to build a stable communication channel with engineers who can work efficiently with users, and one for manufacturing technology and processes that can accommodate change and inputs from diverse users.

However, at the same time, learning-by-interaction can help firms stay abreast of the latest information and technological advances in the field, make timely well-informed decisions, and quickly adapt to the fast rate of change in the market place (Eisenhardt & Martin, 2000). The key to this rationale is that the connection to the outer world is provided by the users who bring in new perspectives on technology and market change.

The manufacturer's timely response with interdependent information is another important factor that proved to be related to the design and lead time in my study. This finding addresses a more micro, inner working of the learning mechanism described in this paper. Progressive problem-solving described in the early part of this paper leads to highly uncertain problem-solving paths. The interdependence between users' needs and the manufacturing process can only unfold as the joint problem solving progresses. This paper posits that with the inherent highly unpredictable interdependence between the

users and the manufacturer, thanks to the two parties' progressive problem-solving, the best way for the manufacturer to deal with the interdependence is to respond more quickly to design changes. Another way to deal with this problem is to decouple the interdependent information as much as possible *ex ante* and use a more automated method such as the user innovation toolkit to respond to design changes more timely and responsively (von Hippel & Katz, 2002). In the user innovation toolkit which I will describe in detail in Chapter 5, users can be given detailed information that automatically changes accordingly with all design changes. Therefore, the responsiveness discussed in this paper relates to a more practical situation.

4.6. Conclusions

The space in which a manufacturer and diverse users interact and continually learn from each other is a very interesting area to investigate. Many firms are trying to incorporate innovation derived from the user and creative users' community activities that are happening outside the firms' boundaries. For example, IBM is trying to tap into the creative forces of open source communities. Innocentive is trying to tap into the users' problem-solving capabilities. Threadless is trying to tap into the users' creative design capabilities. All these examples show that studies focusing on the interface between a firm and its users, their interactive problem-solving, and their learning outcome will be an increasingly more interesting area for both scholars and practitioners alike.

This study lays out the foundation for research on learning-by-interaction that resides between learning-by-doing and learning-by-using. Further studies on this area should be conducted to tie theories of organizational learning, user innovation, and dynamic capabilities, and to identify a firm-specific capabilities in this area. I hope that these studies could guide scholars to see how companies can innovate *together* with their users.

References

Adler, P. S. & Clark, K. B. 1991. Behind the Learning-Curve - a Sketch of the Learning-Process. ***Management Science***, 37(3): 267-281.

Alexander, C. 1964. ***Notes on the Synthesis of Form***. Cambridge, MA: Harvard University Press.

Allen, T. 1966. Studies of the Problem-Solving Process in Engineering Design. ***IEEE Transactions on Engineering Management***, EM-13(2): 72-83.

Allen, T. J. 1977. ***Managing the Flow of Technology: Technology Transfer and the Dissemination of Technological Information within the R&D Organization***. Cambridge, Mass.: MIT Press.

Anzai, Y. & Simon, H. A. 1979. Theory of Learning by Doing. ***Psychological Review***, 86(2): 124-140.

Argote, L., Beckman, S. L., & Epple, D. 1990. The Persistence and Transfer of Learning in Industrial Settings. ***Management Science***, 36(2): 140-154.

Argote, L. & Epple, D. 1990. Learning-Curves in Manufacturing. ***Science***, 247(4945): 920-924.

Argote, L. 1999. ***Organizational Learning: Creating, Retaining, and Transferring Knowledge***. Boston: Kluwer Academic.

Argyris, C. & Schön, D. A. 1978. ***Organizational Learning***. Reading, Mass.: Addison-Wesley Pub. Co.

Arrow, K. 1962. The Economic Implications of Learning by Doing. ***Review of Economic Studies***, 29: 166-170.

Barney, J. 1991. Firm Resources and Sustained Competitive Advantage. ***Journal of Management***, 17(1): 99-120.

Brown, S. L. & Eisenhardt, K. M. 1995. Product Development - Past Research, Present Findings, and Future-Directions. ***Academy of Management Review***, 20(2): 343-378.

Chidambaram, L. & Jones, B. 1993. Impact of Communication Medium and Computer Support on Group Perceptions and Performance - a Comparison of Face-to-Face and Dispersed Meetings. ***Mis Quarterly***, 17(4): 465-491.

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

Clark, K. B. & Wheelwright, S. C. 1993. ***Managing New Product and Process Development: Text and Cases***. New York: Free Press.

Cooper, R. G. 1990. Stage-Gate Systems - a New Tool for Managing New Products. ***Business Horizons***, 33(3): 44-54.

Cramton, C. D. 2001. The Mutual Knowledge Problem and Its Consequences for Dispersed Collaboration. ***Organization Science***, 12(3): 346-371.

Cummings, J. N. 2004. Work Groups, Structural Diversity, and Knowledge Sharing in a Global Organization. ***Management Science***, 50(3): 352-364.

Dutton, J. M. & Thomas, A. 1984. Treating Progress Functions as a Managerial Opportunity. ***Academy of Management Review***, 9(2): 235-247.

Edmondson, A. 1999. Psychological Safety and Learning Behavior in Work Teams. ***Administrative Science Quarterly***, 44(2): 350-383.

Edmondson, A. C. & Mcmanus, S. E. 2007. Methodological Fit in Management Field Research. ***Academy of Management Review***, 32(4): 1155-1179.

Eisenhardt, K. M. & Tabrizi, B. N. 1995. Accelerating Adaptive Processes - Product Innovation in the Global Computer Industry. ***Administrative Science Quarterly***, 40(1): 84-110.

Eisenhardt, K. M. & Martin, J. A. 2000. Dynamic Capabilities: What Are They? ***Strategic Management Journal***, 21(10-11): 1105-1121.

Finholt, T. & Sproull, L. 1990. Electronic Groups at Work. ***Organization Science***, 1(1): 41-64.

Frischmuth, D. & Allen, T. 1969. A Model for the Description and Evaluation of Technical Problem Solving. ***IEEE Transactions on Engineering Management***, Em-16(2): 58-64.

Glaser, B. & Strauss, A. 1967. ***The Discovery of Grounded Theory: Strategies of Qualitative Research***. London: Wiedenfeld and Nicholson.

Golden-Biddle, K. & Locke, K. D. 1997. ***Composing Qualitative Research***. Thousand Oaks, Calif.: Sage Publications.

Griffin, A. & Hauser, J. R. 1993. The Voice of the Customer. ***Marketing Science***, 12(1): 1-27.

Grinter, R. E., Herbsleb, J. D., & Perry, D. E. 1999. The Geography of Coordination: Dealing with Distance in R&D Work. ***Proceedings of the international ACM SIGGROUP conference on Supporting group work***: 306-315.

Gruber, H. 1994. The Yield Factor and the Learning-Curve in Semiconductor Production. ***Applied Economics***, 26(8): 837-843.

Habermeier, K. F. 1990. Product Use and Product Improvement. ***Research Policy***, 19(3): 271-283.

Hauser, J. R. & Clausing, D. 1988. The House of Quality. ***Harvard Business Review***, 66(3): 63-73.

Hayes, R. H., Wheelwright, S. C., & Clark, K. B. 1988. ***Dynamic Manufacturing: Creating the Learning Organization***. New York
London: Free Press;
Collier Macmillan.

Herbsleb, J. D., Mockus, A., Finholt, T. A., & Grinter, R. E. 2000. Distance, Dependencies, and Delay in a Global Collaboration. ***Proceedings of the 2000 ACM conference on Computer supported cooperative work***: 319-328.

Jarvenpaa, S. L. & Leidner, D. E. 1998. Communication and Trust in Global Virtual Teams. ***Journal of Computer-Mediated Communication***, 3(4).

Leonard-Barton, D. 1992. Core Capabilities and Core Rigidities - a Paradox in Managing New Product Development. ***Strategic Management Journal***, 13: 111-125.

Levitt, B. & March, J. G. 1988. Organizational Learning. ***Annual Review of Sociology***, 14: 319-340.

Lieberman, M. B. 1984. The Learning-Curve and Pricing in the Chemical-Processing Industries. ***Rand Journal of Economics***, 15(2): 213-228.

Lorenzoni, G. & Lipparini, A. 1999. The Leveraging of Interfirm Relationships as a Distinctive Organizational Capability: A Longitudinal Study. ***Strategic Management Journal***, 20(4): 317-338.

Malone, T. W. & Crowston, K. 1994. The Interdisciplinary Study of Coordination. ***Acm Computing Surveys***, 26(1): 87-119.

Malone, T. W. 2004. ***The Future of Work: How the New Order of Business Will Shape Your Organization, Your Management Style, and Your Life***. Boston, Mass.: Harvard Business School Press.

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

Marples, D. L. 1961. The Decisions of Engineering Design. ***IEEE Transactions on Engineering Management***, 2: 55-71.

McDonough, E. F., Kahn, K. B., & Barczak, G. 2001. An Investigation of the Use of Global, Virtual, and Colocated New Product Development Teams. ***Journal of Product Innovation Management***, 18(2): 110-120.

McGrath, J. E. & Hollingshead, A. B. 1993. ***Groups Interacting with Technology: Ideas, Evidence, Issues and an Agenda***: Sage Publications, Inc. Thousand Oaks, CA, USA.

Miles, M. B. 1979. Qualitative Data as an Attractive Nuisance - Problem of Analysis. ***Administrative Science Quarterly***, 24(4): 590-601.

Nelson, R. R. 2000. Why Do Firms Differ, and How Does It Matter?" ***The Theory of the Firm: Critical Perspectives on Business and Management***.

Newell, A. & Simon, H. A. 1972. ***Human Problem Solving***. Englewood Cliffs, N.J.: Prentice-Hall.

O'Leary, M. B. & Cummings, J. N. 2007. The Spatial, Temporal, and Configurational Characteristics of Geographic Dispersion in Teams. ***Mis Quarterly***, 31(3): 433-452.

Owen-Smith, J. & Powell, W. W. 2004. Knowledge Networks as Channels and Conduits: The Effects of Spillovers in the Boston Biotechnology Community. ***Organization Science***, 15(1): 5-21.

Peteraf, M. A. 1993. The Cornerstones of Competitive Advantage - a Resource-Based View. ***Strategic Management Journal***, 14(3): 179-191.

Pisano, G. P. 1994. Knowledge, Integration, and the Locus of Learning - an Empirical-Analysis of Process-Development. ***Strategic Management Journal***, 15: 85-100.

Pisano, G. P. 1996. Learning-before-Doing in the Development of New Process Technology. ***Research Policy***, 25(7): 1097-1119.

Pisano, G. P., Bohmer, R. M. J., & Edmondson, A. C. 2001. Organizational Differences in Rates of Learning: Evidence from the Adoption of Minimally Invasive Cardiac Surgery. ***Management Science***, 47(6): 752-768.

Powell, W. W., Koput, K. W., & SmithDoerr, L. 1996. Interorganizational Collaboration and the Locus of Innovation: Networks of Learning in Biotechnology. ***Administrative Science Quarterly***, 41(1): 116-145.

Prahalad, C. K. & Ramaswamy, V. 2004. ***The Future of Competition: Co-Creating Unique Value with Customers***. Boston, Mass.: Harvard Business School Pub.

Rosenberg, N. 1982. ***Inside the Black Box: Technology and Economics***. Cambridge [Cambridgeshire]; New York: Cambridge University Press.

Simon, H. A. 1973. The Structure of Ill Structured Problems. ***Artificial Intelligence***, 4: 181-201.

Simon, H. A., Dantzig, G. B., Hogarth, R., Plott, C. R., Raiffa, H., Schelling, T. C., Shepsle, K. A., Thaler, R., Tversky, A., & Winter, S. 1987. Decision-Making and Problem-Solving. ***Interfaces***, 17(5): 11-31.

Strauss, A. L. 1987. ***Qualitative Analysis for Social Scientists***. Cambridge [Cambridgeshire]; New York: Cambridge University Press.

Suh, N. P. 1990. ***The Principles of Design***. New York: Oxford University Press.

Teece, D. J., Pisano, G., & Shuen, A. 1997. Dynamic Capabilities and Strategic Management. ***Strategic Management Journal***, 18(7): 509-533.

Teece, D. J. 2007. Explicating Dynamic Capabilities: The Nature and Microfoundations of (Sustainable) Enterprise Performance. ***Strategic Management Journal***, 28(13): 1319-1350.

Thomke, S. H. 1998. Managing Experimentation in the Design of New Products. ***Management Science***, 44(6): 743-762.

Thompson, J. D. 1967. ***Organizations in Action; Social Science Bases of Administrative Theory***. New York: McGraw-Hill.

Ulrich, K. T. & Eppinger, S. D. 2004. ***Product Design and Development*** (3rd ed.). Boston: McGraw-Hill/Irwin.

Van den Bulte, C. & Moenart, R. K. 1998. The Effects of R&D Team Co-Location on Communication Patterns among R&D, Marketing, and Manufacturing. ***Management Science***, 44: 1-18.

von Hippel, E. 1988. ***The Sources of Innovation***. New York: Oxford University Press.

von Hippel, E. 1990. Task Partitioning - an Innovation Process Variable. ***Research Policy***, 19(5): 407-418.

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

von Hippel, E. & Tyre, M. J. 1995. How Learning by Doing Is Done - Problem Identification in Novel Process Equipment. ***Research Policy***, 24(1): 1-12.

von Hippel, E. & Katz, R. 2002. Shifting Innovation to Users Via Toolkits. ***Management Science***, 48(7): 821-833.

von Hippel, E. 2005. ***Democratizing Innovation***. Cambridge, Mass.: MIT Press.

Warkentin, M. E., Sayeed, L., & Hightower, R. 1997. Virtual Teams Versus Face-to-Face Teams: An Exploratory Study of a Web-Based Conference System*. ***Decision Sciences***, 28(4): 975-996.

Wernerfelt, B. 1984. A Resource-Based View of the Firm. ***Strategic Management Journal***, 5(2): 171-180.

Wright, T. P. 1936. Factors Affecting the Costs of Airplanes. ***Journal of Aeronautical Science***, 3: 122-128.

Yelle, L. 1979. The Learning Curve: Historical Review and Comprehensive Survey. ***Decision Sciences***, 10(2): 302-328.

CHAPTER 5: MITIGATION OF LANGUAGE TRANSFER VIA CREATION OF NEW LANGUAGE

5.1. Introduction

Through Chapters 2 and 4, I examined 1) how the extant literature views boundary spanning communication and collaboration, 2) how the language transfer problem manifests itself at the user-manufacturer boundary, 3) how the language transfer problem is mitigated during joint product development projects, and show 4) some empirical evidence that the local learning at the user boundary of the firm exists, and 5) evidence of the importance of responsive exchanges of interdependent information.

In Chapter 5, I will present yet another way to mitigate the language problem at the user-manufacturer boundary – through the creation of a new language. By drawing theories and cases from innovation toolkit literature (Thomke & von Hippel, 2002a; von Hippel, 2001; von Hippel & Katz, 2002) and literature on local trading zone (Galison, 1997; Galison & Stump, 1996), I will explain how the creation of a new "middle" language could help mitigate the language transfer problem.

In the following section, I will discuss the general aspects of the toolkit mechanism and the trading zone, and then move on to cases that illustrate the mechanisms in which a new language is created.

5.2. Literature Review

5.2.1. User-innovation Toolkit

The "users as innovators" concept has been well known to researchers who study technological innovation (von Hippel, 1988; von Hippel, 2005). With the rapid development of communities and ever increasing collaboration on-line, we see users innovating with their individual creativity combined with the collective power of individuals sharing their knowledge (Lakhani & von Hippel, 2003). Some companies simply fail to recognize the power of users. Others engage themselves with user communities to make use of their capability to innovate, but more often than not, they experience great difficulty in successfully doing so.

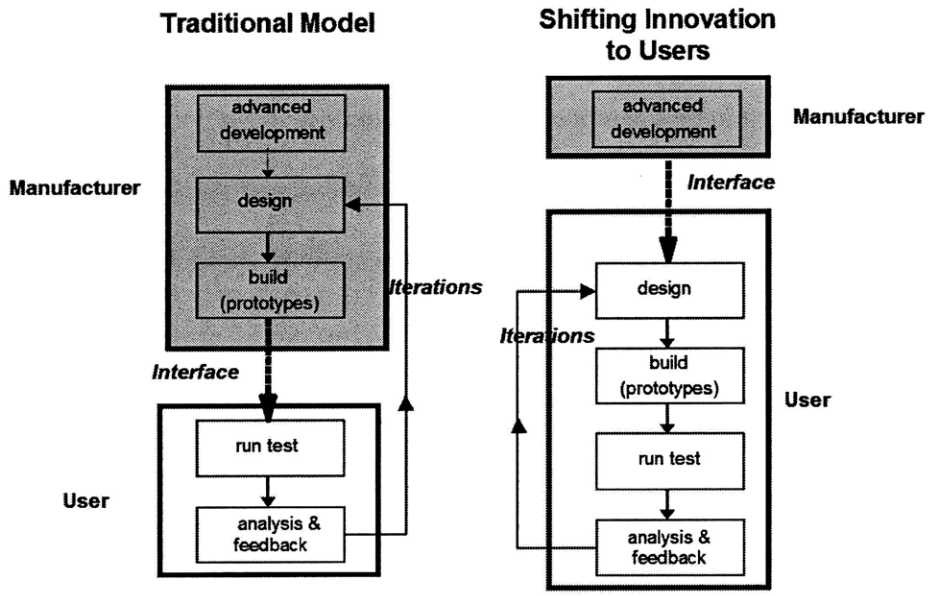
Many different methods were developed in order to understand what users require for product features (Ulrich & Eppinger, 2004) and how to identify innovations by collaborating with lead users (Urban & von Hippel, 1988). But the actual methodology to utilize user's innovation capabilities and to link them to the manufacturer's innovation capabilities is less well known to both academia and practitioners.

One such approach has been known as the "user-innovation toolkit" approach (von Hippel & Katz, 2002). The user-innovation toolkit approach shifts the locus of innovation to the user side, enabling users to combine different design primitives to create a product or product features that meet their needs (Thomke & von Hippel, 2002b). What

distinguishes the user-innovation toolkit from the traditional model of innovation is that it supports the process of design, build, and test by users (Figure 5.1). Going through the iterative process, users can benefit from learning-by-doing by gaining experiences and validating their ideas about innovation. User innovation toolkits also provide a large solution space. In this new innovation environment, users can design and build a new product based on their experiences and needs which are thought to be highly "sticky" to transfer to new entities (von Hippel, 1994). Therefore, the user innovation toolkit brings the need-related information with the necessary problem-solving skills together at one place to enable new product designs.

In the process of creating this new type of an environment for user-innovation, a new type of language is often created. The toolkit can be seen as a way of resolving user-manufacturer boundary issues by shifting the problem-solving locus to users. In the following section, I will describe the nature of language issues presented to the toolkit developer and how they overcome the language difference by creating a new type of language.

Figure 5.1. Shifting the Locus of Innovation to Users via Toolkit



** Modified from Thomke & von Hippel (2002)*

5.2.2. Language Issues in Toolkits

The main issues involving the user innovation toolkit are related to the toolkit "language." Von Hippel and Katz (2002) identified the toolkit language as the major area that should be considered in designing the toolkit. A user friendly language that allows the users to use their existing experience can significantly increase the utility of the toolkit by minimizing the learning cost that can be incurred in a less user-friendly language. Von Hippel and Katz also gave an example of a custom integrated circuit

design and argued that users could use their own customary language - in this case, Boolean algebra - and thus, collaboration using the user innovation toolkit was possible without incurring a high learning cost. Users are familiar with the desired context of the product and have much knowledge about what functions they desire in the product. They are also the experts in making necessary trade-offs between cost and functionality that are familiar to them. If they can be equipped with a toolkit that supports the problem-solving in their own language, then the locus of the innovation can be successfully shifted to their side while the manufacturers can fully enjoy the product design inputs from the users.

The benefit of the user innovation toolkit also depends on the seamless translation from the user design language into the language required by the intended production systems. The designs that users create should be translated into a format that manufacturers can use in the production process. If the manufacturer has to reinterpret what the users created, there is no added value to the toolkit approach. The user innovation toolkit is a way to minimize the exchange of need-related information between users and manufacturers. If the translation is not smooth, the effectively separated innovation tasks lose their benefit of task partitioning (von Hippel, 1994; von Hippel & Katz, 2002).

Manufacturers usually initiate the development of a toolkit[11]. Initially, manufacturers create it and decide which user groups they want to focus on. Most of the toolkits are developed and improved by the manufacturers due to its tight coupling with the intended production system. User participation is still very critical since it enables the recognition

[11] More and more user-developed toolkits are observed in various fields – or at least significantly modified by the users. For example, Lego user communities have many examples of user-oriented toolkits.

of the language difference and gives the manufacturers a sense of direction for the toolkit to evolve. For example, the users work for the manufacturers by adding module libraries.

In this sense, the toolkit should be considered as the communication medium between two or more separate parties who have different cognitive schemes. These two different cognitive schemes are manifested in the language structure of the toolkit. Therefore, toolkits provide a unique opportunity to observe how users and manufacturers interact with each other, and to see what issues emerge as both parties communicate with each other to come up with a new product design.

5.2.3. Trading Zone

As discussed in Chapter 3, a language transfer problem can be mitigated by individual efforts and social interaction, in which individuals constantly interpret meanings in other communities, separate meanings out of social and physical settings, and embed and interpret meanings from the boundary object. In addition to this process, a new type of language sometimes emerges during this local interaction. This way of bridging the language gap is well described in the study of the history of scientific collaboration.

Galison (1997) coined the term 'trading zone' to explain that the same kind of interactions happen between different groups of physicists such as theorists, experimentalists, and instrument engineers. He defined the trading zone as the 'intermediate domain in which procedures can be coordinated locally even where broader meanings clashed (p.46).' Despite people's vast differences in how they view the world,

they come up with a coordination mechanism – rules of exchange in his term - that enables them to communicate with each other successfully. This coordination mechanism includes language primitives that bridge across boundaries and common domains – structural arrangement, both social and physical (pp.827-830) - where interaction takes place. Less visible transfers take place via an architectural arrangement and data handling created by different parties involved. Galison described this process as follows.

> *(p.783) ... But here we can learn from the anthropologists who regularly study unlike cultures that do interact, most notably by trade. Two groups can agree on rules of exchange even if they ascribe utterly different significance to the objects being exchanged; they may even disagree on the meaning of the exchange process itself. Nonetheless, the trading partners can hammer out a local coordination despite vast global differences. In an even more sophisticated way, cultures in interaction frequently establish contact languages, systems of discourse that can vary from the most function-specific jargons, through semi-specific pidgins, to full-fledged creoles rich enough to support activities as complex as poetry and metalinguistic reflection ... in focusing on local coordination, rather than global meaning, one can understand the way engineers, experimenters, and theorists interact.*

Galison (1997) emphasized the local and context-specific nature of collaboration and described how a new kind of language emerges in that effort. During World War II, situation theorists, experimentalists, and instrument engineers were brought together in a

large war time project. In an effort to come up with the equivalent circuits for waveguides (long hollow metal boxes used for guiding electromagnetic waves, light, or sound waves), Schwinger, who was at the time a MIT Radiation Lab theorist, came up with a set of equivalent circuits that corresponded to physical waveguides. Before this new language was devised, all the currents of physical discontinuities such as protrusion, gaps, and dividers in the waveguide and the complicated fields surrounding those discontinuities had to be calculated. But after the new language emerged, engineers could come up with new kinds of microwave circuits combining different language primitives. In some ways, they created new language primitives linking their own language of field theory to the language of electrical engineering.

Vaughan's study on NASA (1993) illustrated the communication between NASA and its contractor personnel that took place, despite the vast differences from testing procedures to facilities to their engineering philosophies (p. 921). To bridge the gap between two different local languages, they devised a new language – government rules, standard procedures, new vocabularies and acronyms, safety regulations, documentary style recording, equipments, personnel acquisition system and other written documents - that restricted the full description of concepts and theoretical arguments of experimental practices for the purpose of local coordination. Along with the physically collocated domain and shared administrative structure, this new local coordination mechanism enabled the two disparate parties to engage in collaboration.

In both of these cases, what connects the disparate communities of different meaning systems is described as a new system of language that bridges the gap between parties involved in the communication and collaboration.

5.3. Creation of New Language System

5.3.1. One-to-one Translation

The user and the manufacturer can translate without an error if the user has a language with primitives that can be translated one-for-one into the manufacturer's language. The basic level one-to-one translation can be observed in the area of digital semiconductor circuits (Thomke, 1995).

A programmable logic device (PLD) is an electronic component that is used for reconfigurable digital circuits. Unlike the logic gates which have fixed functions, PLDs can be programmed as customers want. There are different ways in which PLDs can be achieved. One way is to design the circuit in Boolean equations and translate them into a fuse pattern to program that part. This fuse pattern is printed on a device such as a programmable array logic (PAL). Another approach is field programmable gate arrays (FPGA). FPGAs use a gate array circuit which is a prefabricated silicon chip circuit with no particular functions. Customers can then add layers of metal interconnected to the chips, allowing them to design and create a custom chip.

The translation in this case happens at the Boolean algebraic level. In both methods, the user only needs to come up with proper Boolean equations in order to create a customized chip. In the 1980s, schematics were the only method that users could use to represent the Boolean logic. Once the Boolean equations were defined by the users, they were used as inputs for the PLDs to create custom design ASICs. There is no loss of

information since both the users and the manufacturers have shared their understandings of the primitives and use them when they communicate to come up with new products.

This one-to-one translation mechanism is described in Figure 5.2. Users express their needs in their own language while the manufacturers get inputs in their own language. What makes this transition possible is the one-to-one match that should be in place.

.5.3.2. Extension of One-to-one Match

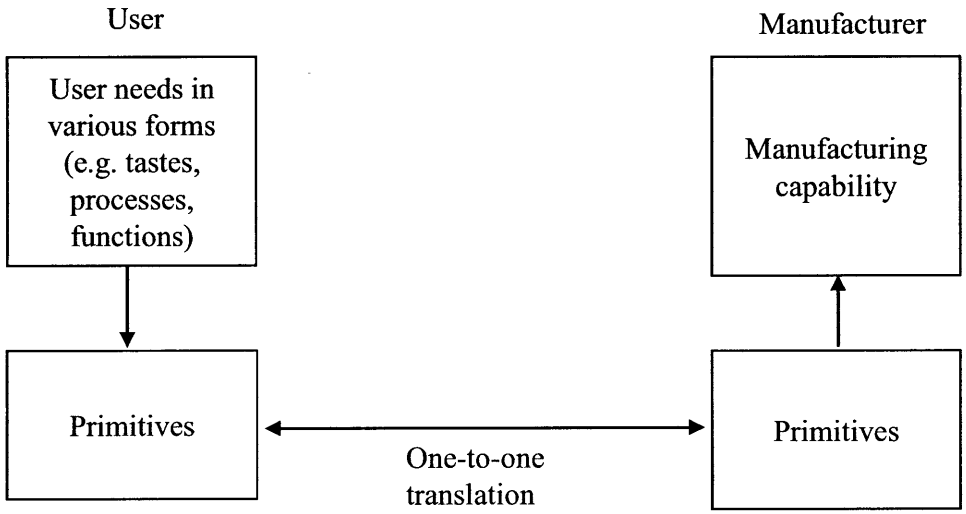
An interesting phenomenon can be observed in this same field I described in the previous section. Once a basic one-to-one translation is established, a design can be carried out at a more complex level involving a combination of many primitives that can be individually translated on an one-to-one basis. For example, a design can be carried out in terms of op amps (operational amplifiers) instead of individual logic gates. This makes a translatable design easy for certain users.

Recently, at a more abstract level, higher level languages such as hardware description language (HDL) – the equivalent of software's assembly language – are used. Even higher level languages – the equivalent of high level software language such as C or C++ - are developed and used these days. The purpose is to make these languages available to a wider audience such as software engineers rather than traditional hardware engineers who are comfortable using the lower level language.

All of these efforts to come up with a higher level language attest to the argument that once the basic one-to-one relationship is established, it can be abstracted at a level

that users can easily respond to. Therefore, the basic level translation between the user and the manufacturer is critical not only for translation without error between two economic actors, but is also important to make the language more accessible by users.

Figure 5.2. Errorless One-to-one Translation



5.4. Cases and Findings

In management literature, there are many cases in which a new language scheme is created in order to provide a common ground for communication. However, the process in which a new language scheme is developed or emerged is less well known. In the following examples, a new language scheme with new primitives – the basic unit of communication – is created due to a lack of a one-to-one match in an existing language scheme. Then one person or a group of people who see the possibility of creating a new language scheme will invest their own time and resources for creating a new language scheme.

Generalized findings from the observation of these examples (Table 5.1) are as follows.

Generalized findings:

1. New language scheme is designed by a single person or a group of people who has the knowledge on both sides of the translation.
2. New language scheme sometimes creates a new level of translation that did not exist previously.
3. In order to translate at the newly created translation level, one or both sides need to learn the new language. This leaning process is usually a matching process between the existing knowledge and the new language scheme.

4. Explicitly expressing one's need or solution information is not enough for the translation; the need and solution information might be so tightly embedded in their physical settings, efforts should be made to extract the information from these settings.

5. New language scheme enables iterative problem-solving, creating a tight connection between existing tacit knowledge and the new, more explicit format. Describing tacit knowledge to another party is difficult; but working with explicit forms to express tacit knowledge can be feasible in many situations since iterative problem-solving can be used for transforming tacit knowledge into an explicit form.

6. New language scheme sometimes removes the role of translators by changing the way the translation is done.

Table 5.1. Summary of Literature on New Language Creation

Case/Source	Initial User Language of Design And feedback mechanism	Initial Manufacturer Language of Design and feedback	New design language and feedback with toolkit
Waveguides design (Galison, 1997)	Equations and languages in physics	Electrical circuits	Equivalent circuits
Integrated circuit design (Thomke & von Hippel, 2002b)	Boolean Algebra	Digital Gate Logic + prototype	A set of design toolkit
Nestle Custom Food (von Hippel & Katz, 2002)	Built on Culinary School ingredients and processes with tasting feedback	Factory design language built on factory ingredients and processes. Prototypes sent to user for tasting and feedback to correct flavor	A set of factory-specific primitives. User could adjust proportion of primitives in recipe to get the desired taste. Taste toolkit sample
IFF flavor toolkit (von Hippel & Katz, 2002)	Specify taste he wanted in user "tastes like" language (e.g. peach)	Chemicals that taste is made from (e.g. Butyric acid) Sample to customer for tasting	Specify taste he wants in terms of familiar flavor primitive component tastes – a complete set. Gets sample to taste

5.4.1. Waveguides case

In the case of the physicists working on the waveguides (Galison, 1997), physicists and instrument engineers communicated based on the physical forms *before* the new language was created. When physicists came up with new scientific findings through theory development or experiments, these results were expressed in the waveguides in the

form of physical discontinuities – such as protrusion, gaps and dividers. Then, these physical discontinuities were interpreted by electrical engineers who could create equivalent electrical circuits. In this process, interpretation was rather rugged in the sense that the changes in the physical settings should have been communicated between the physicists and the electrical engineers. In this case, knowledge that was necessary to translate from one side to another was distributed since the physicists were the ones who understood the physics of waveguides (similar to need information) and the electrical engineers were the ones who could create the electrical circuits according to their physical findings (similar to solution information). Neither of these parties had full information to translate successfully.

However, *after* Schwinger came up with a set of equivalent circuits corresponding to the physical discontinuities (Figure 5.3), communication happened at the very concrete level (a more primitive, lower level). The physicists and electrical engineers could both find the connection between physical discontinuities and the corresponding circuits which enhanced the communication significantly. Rather than translating at the more abstract level where two different knowledge schemes were not shared, communication at the more concrete level where a one-to-one match was established was much easier and created less error in translation (Figure 5.4). Although it took some time to match up what the two parties knew, once Schwinger came up with the new language scheme, other physicists and engineers contributed to the extension of the language scheme.

Figure 5.3. Physical Waveguides and Equivalent Circuits (Adapted from Galison, 1997)

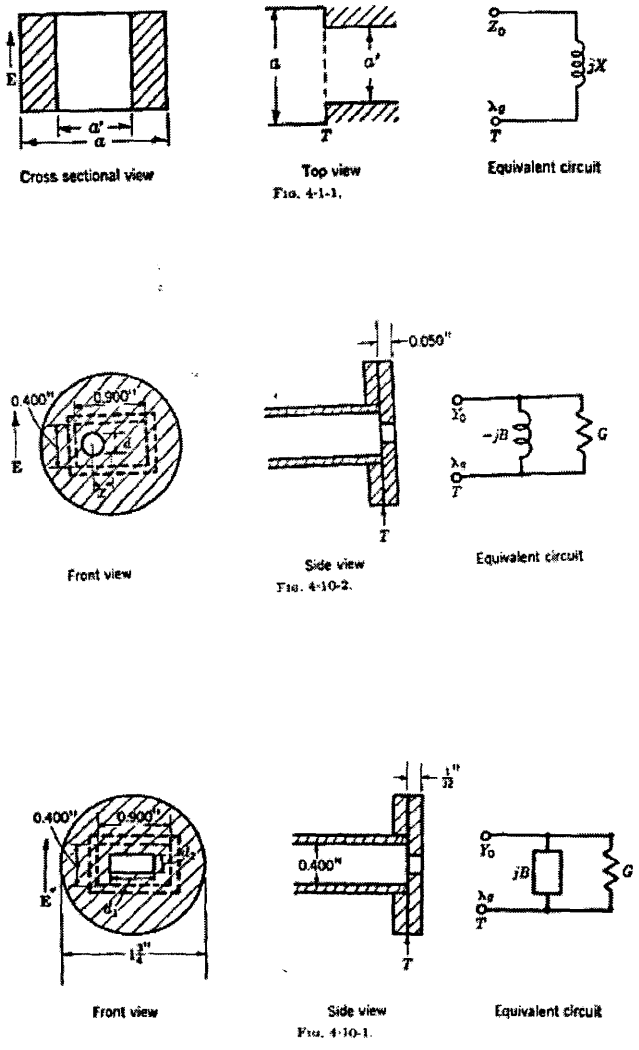
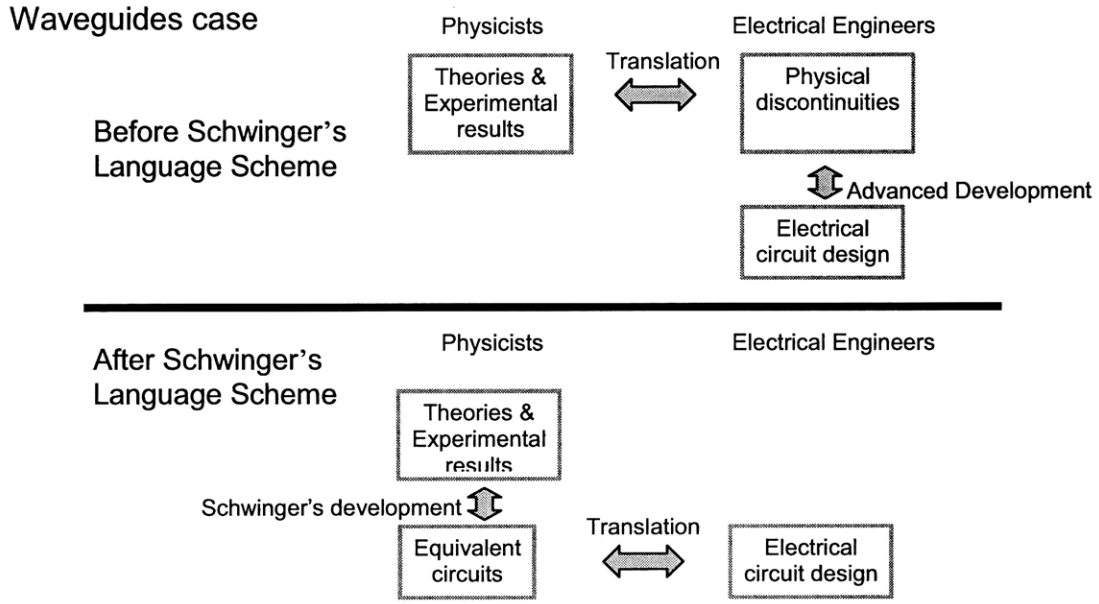


Figure 5.4. Waveguides Case



5.4.2. Integrated Chip (IC) Design Case

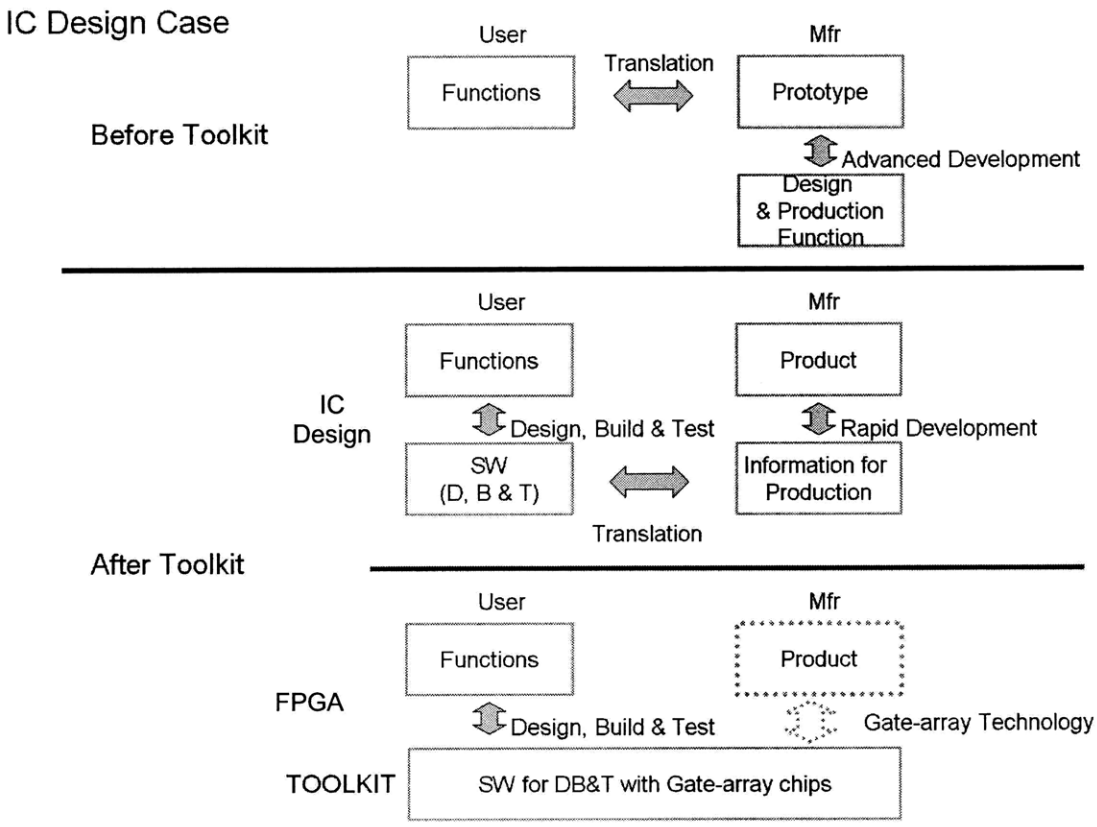
Before the introduction of the design toolkit for the IC design, functional requirements from users had to be communicated back and forth between the users and the focal manufacturer until the prototypical circuit met the users' requirements. This is a very costly iteration in which many errors in translation can be hidden until the actual

deployment of prototypes by users as shown in Chapter 3. The production of the IC was also problematic in that the prototypes should be used as the guideline for setting up the production line. In that process, another layer of translation existed between design engineers who interpreted user requirement and the production engineers who actually set up the production process.

But after the introduction of the IC design toolkit, users could iteratively work with their own design via a software toolkit, through which the information on the IC design was directly translated into a form that the manufacturer could understand and use for chip production. In this case, the toolkit enabled language translation from functional requirements into design information that could be used in production. Engineers on the user side now had to learn the use of the software toolkit, but once the users learned the new language scheme, they enjoyed the benefit of iterative problem-solving that enabled a tight connection between the functional requirement and the actual circuit design since they all happened o the users' side.

Field Programmable Gate Array (FPGA) incorporated another layer of translation into the new language scheme. FPLD eliminated the need for translation from design engineers to production engineers in which some information can be lost in translation. In this language scheme, users' functional requirements could be translated into the final products with minimum interpretation or intervention from manufacturers. Therefore, users could get exactly what they wanted since the design, build, and test sequence was all done on the user side.

Figure 5.5. Integrated Chip Design Case



5.4.3. Nestle Custom Food Case

In the Nestle Custom Food case, users –in this case, restaurant chefs - have a very delicate need to create the exact taste they want. Before the development of a custom food toolkit, Nestle engineers need to understand and translate this very delicate taste information into the form of food products. When the prototypical products are

developed, the users test the product to see whether the engineers created the taste they initially wanted. In this process, there is great room for translation errors since the taste is something that is not easily translated into an explicit form of information.

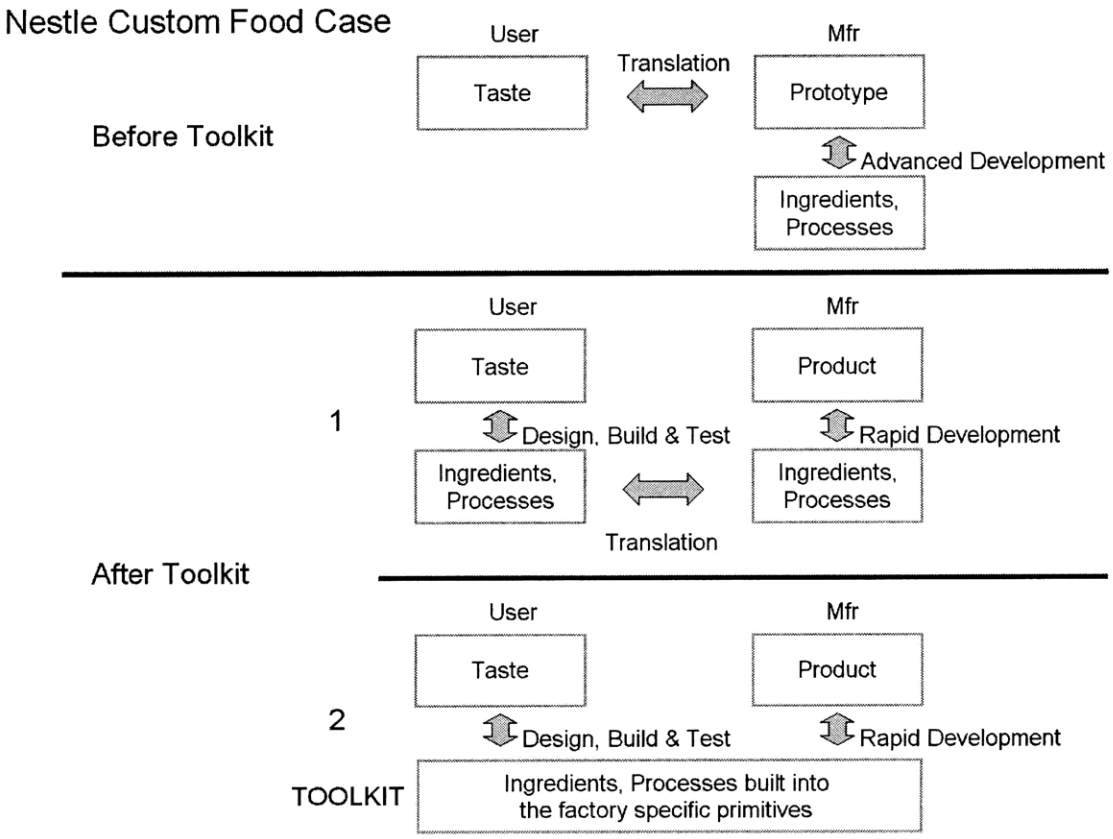
The tacit knowledge of restaurant chefs can be explicitly expressed in the form of the final food they can create. But in this process, this translation process is tightly embedded in the ingredients and the equipments the chefs use in their own restaurants. Even with the explicitly expressed need information in the form of the final food, the manufacturer will have to translate that final food created by chefs into the ingredients and processes used on the production floor.

Nestle solved this problem by creating a new level of translation with food pouches that could be mixed and matched according to users' needs. Chefs worked with these new primitives in order to make the final food they wanted to create. Since the primitives were already tightly connected to the production processes, the explicit information created by working with new primitives could be translated to the manufacturer with fewer errors.

Chefs had to go through the learning process to match up their existing knowledge about creating food with the new primitives. But once they learned the new primitives, the error-reduced translation and the tighter fit with the production technology could be beneficial to both the users and the manufacturers. Hypothetically, users can create new language primitives by working with the factory environment that is much closer to their original problem-solving environment. But when users have their own problem-solving environment in the kitchen, each language scheme that fits well with each user's problem-solving environment can create a set of language schemes that the manufacturer has to accommodate in their production environment. The cost of creating a number of

language schemes is also not very efficient. However, when the manufacturer does not initiate a new language creation, the users will often initiate this process, which will result in different versions of language schemes, a situation that is often observed in the open source software (OSS) community (Lakhani & von Hippel, 2003).

Figure 5.6. Nestle Custom Food Case



5.4.4. International Flavor and Fragrances, Inc. (IFF) case

In the International Flavor and Fragrances (IFF) case, the manufacturer of flavors and fragrances has to interact with its users to develop custom flavors by iteratively going back and forth until there is a final prototype that fits the users' needs. The users have many different ways of expressing their needs while the manufacturer has its own ways. IFF even uses synesthesia[12] to express a new flavor or fragrance. For example, very intense colors are used in a sense-evoking picture to express an intense flavor. This means that flavor and fragrance can be expressed in many different ways of communication.

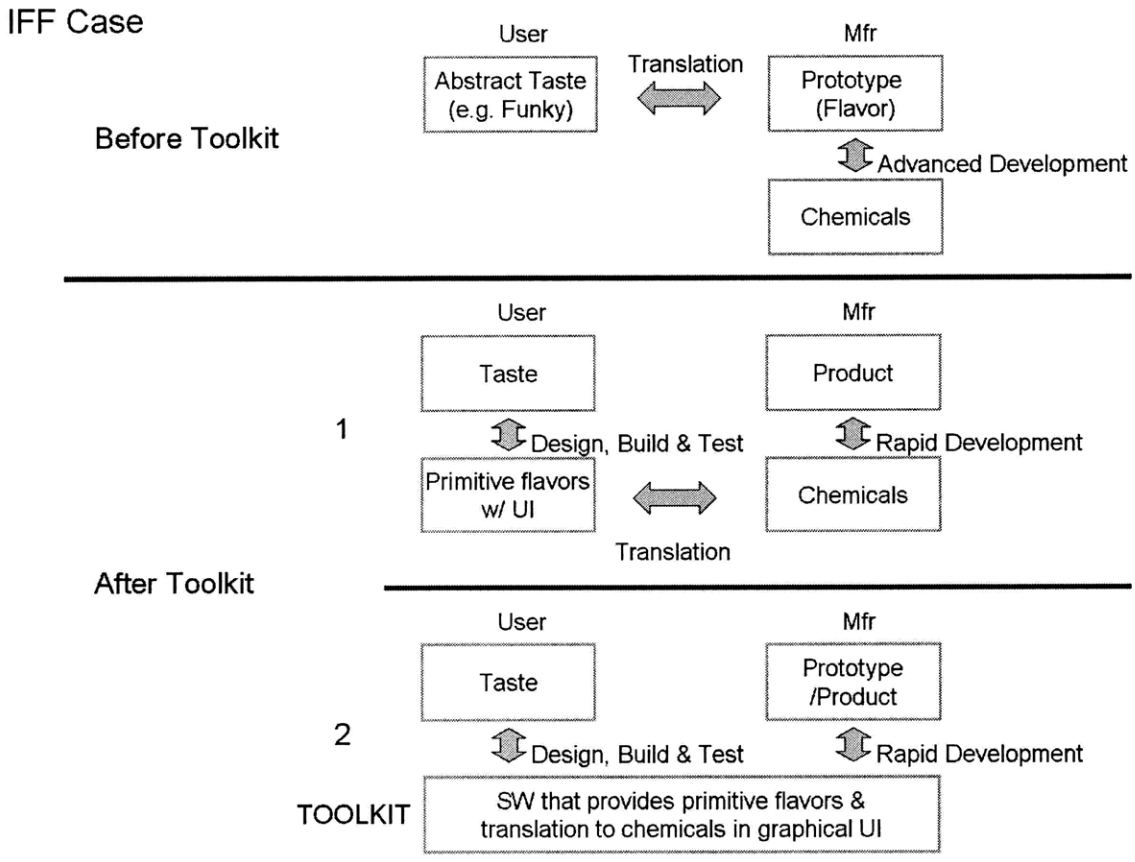
Rather than directly translating the users' needs into flavors, IFF came up with new primitives – such as floral, creamy, or fruity taste – that could be mixed and matched in different portions to create a new flavor. The basic assumption was that these basic primitives were more familiar to the users. Then, these basic primitives were translated into the chemicals that were necessary to create these flavors. The users could view the different compositions as they experimented with different flavors in the newly created toolkit. Testing was done by tasting the prototypes that were created in much shorter time due to the enhanced translation.

Primitives in this case are developed by the manufacturer without much attention to the individual language difference that I discussed in the Fidelity Investment case

[12] Synesthesia is a neurologically based phenomenon in which stimulation of one sensory or cognitive pathway leads to automatic, involuntary experiences in a second sensory or cognitive pathway (Cytowic, 2005)

(Chapter 2). Manufacturers need to put some efforts into finding the general language scheme of the users and the specificity of the individual language scheme as well. If the toolkit can accommodate these generalities and specifics of the language, it can be more easily adapted to the users' various language schemes. As shown in Figure 5.7, the manufacturer developed the translation mechanism (after toolkit 1), then implemented it in the toolkit (after toolkit 2). However, the users' specificity was reflected by letting users decide how to translate the mix and match of the flavors (user language) into the actual chemicals.

Figure 5.7. International Flavor and Fragrances Case



References

Cytowic, R. E. 2005. Synesthesia: Perspectives from Cognitive Neuroscience. ***Journal of Consciousness Studies***, 12(4-5): 141-143.

Galison, P. & Stump, D. J. 1996. ***The Disunity of Science: Boundaries, Contexts, and Power***. Stanford, Calif.: Stanford University Press.

Galison, P. 1997. ***Image and Logic: A Material Culture of Microphysics***. Chicago: University of Chicago Press.

Lakhani, K. R. & von Hippel, E. 2003. How Open Source Software Works: "Free" User-to-User Assistance. ***Research Policy***, 32(6): 923-943.

Thomke, S. 1995. ***The Economics of Experimentation in the Design of New Products and Processes***. Unpublished Doctoral Thesis, Massachusetts Institute of Technology, Cambridge, MA.

Thomke, S. & von Hippel, E. 2002a. Customers as Innovators - a New Way to Create Value. ***Harvard Business Review***, 80(4): 74-81.

Thomke, S. & von Hippel, E. 2002b. Customers as Innovators - a New Way to Create Value. ***Harvard Business Review***, 80(4): 74-+.

Ulrich, K. T. & Eppinger, S. D. 2004. ***Product Design and Development*** (3rd ed.). Boston: McGraw-Hill/Irwin.

Urban, G. L. & von Hippel, E. 1988. Lead User Analyses for the Development of New Industrial-Products. ***Management Science***, 34(5): 569-582.

Vaughan, D. 1993. The Role of the Organization in the Production of Techno-Scientific Knowledge. ***Social Studies of Science***, 29(6): 913-943.

von Hippel, E. 1988. ***The Sources of Innovation***. New York: Oxford University Press.

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

von Hippel, E. 2001. Perspective: User Toolkits for Innovation. ***Journal Of Product Innovation Management***, 18(4): 247-257.

von Hippel, E. & Katz, R. 2002. Shifting Innovation to Users Via Toolkits. ***Management Science***, 48(7): 821-833.

von Hippel, E. 2005. ***Democratizing Innovation***. Cambridge, Mass.: MIT Press.

CHAPTER 6: SUMMARY AND CONCLUSION

6.1. Summary of Results

In this chapter, I will briefly summarize the results presented in this thesis. The theoretical framework and the empirical results I have presented in this thesis explored the boundary between a manufacturer and its users. I first looked at the users of a financial services provider to explore the language difference between a manufacturer and its users. I then moved on to examine an observable interaction between the two parties during their joint product development projects. By examining these projects, I identified the process in which language difference creates communication problems and the process in which a language transfer problem can lead to a detrimental effect on the outcome of the product development. This qualitative observation helps to build four testable hypotheses, which are tested in the following sections. In this quantitative analysis, learning-by-interaction is found to exist at the user-manufacturer boundary. At the end of this dissertation, I explore yet another mechanism of language translation using a newly created language scheme.

In **chapter 2**, I build the foundation of the thesis by going over the extant literature on firm boundaries. I identified six different perspectives on firm boundaries: task-oriented, information-processing, transaction cost economics, knowledge-based, technology-oriented, and language-oriented perspectives. While most of these perspectives provide a rationale for how to design the boundaries of a firm, they seldom address the issue of user boundaries. It is partly because customers have been regarded as a totally separate economic actor outside the boundary of a firm. Customers have usually been regarded as the final consumer of the products or services created. However, once

we start looking at the customers as users who use the products and services, we can acquire valuable information out of their experiences. When we look at the customers as innovators, they should be treated as an important source of product-design-related information. Then the language-oriented perspective, which has been mainly targeted towards explaining the within-organizational boundaries among different departments or disciplines, becomes relevant since the focal manufacturer has to engage in communication and collaboration with users as if they are a part of the organization.

Taking the language-oriented perspective, I then move on to an empirical investigation of how a manufacturer deals with the user language difference and how diverse the user language is across the population. By conducting an explorative study at a financial services firm, Fidelity Investment, I identify a long tail of the users' language diversity. This indicates that a substantial amount of commonality and a substantial amount of diversity coexist among the users.

In **chapter 3**, I explore the collaborative problem-solving process that takes place between Protocase, a manufacturer of custom housings for electronic equipment, and its customers during the product development. I apply grounded theory building to develop a process model of how differences in the problem-solving languages used by customers and by Protocase's internal engineering staff can negatively influence the joint product development process between these parties. The core problem is that both the users and the manufacturer are reluctant to reveal the fact that they don't understand each other. This reluctance to reveal their language incomprehension leads to a problematic outcome at the end of the Design-Build-Test cycle if both parties move on without reconciling the language incomprehension.

From the analysis of the actual communication between the manufacturer and its users, I also show how the local learning process can mitigate the language difference. In user-manufacturer collaboration, technical interdependencies between user requirement and manufacturer implementation trigger an interactive local learning process.

In **chapter 4**, I develop a learning model at the user-manufacturer level to further develop the concept of learning-by-interaction drawn from chapter 3. I identify the learning-by-interaction process between a manufacturer and its users in the product development stage. By examining 359 user-manufacturer co-development projects, I demonstrate that a focal manufacturer and its users have a learning curve identical to that observed within the boundary of a firm. But in contrast from what the traditional learning-curve effect suggests, I show that this learning-by-interacting with users benefits the *design* process rather than the *manufacturing* process. To understand the process of learning-by-interaction more deeply, I analyzed 2,365 communication data consisting of emails and phone call records and found that the timely and responsive feedback of interdependent information is critical in the continuous-design problem-solving in this user-manufacturer learning process. The effects of prior templating – problem-solving with the products used against the use context - and distance – both spatial and temporal - on learning were examined as well, but it was revealed that they did not have a significant role in the context of this field study. The result is then discussed to show how this study can contribute to the current literature on dynamic capabilities and organizational learning. I conclude this chapter with a discussion of the direction for future research.

In **chapter 5**, I present the theories and case studies to illustrate a way of bridging the user-manufacturer boundary through creation of a new language scheme. Drawing from the literature on the innovation toolkit and the trading zone, I try to generalize some observations made in four different cases of a new language creation – waveguides, integrated chip design, custom food design, and flavor & fragrance design. The main argument in this chapter is that more basic level primitives should be developed in order to bridge the language gap, while enabling the iterative problem-solving of both manufacturers and users.

6.2. Implications for Theory and Practice

The basic assumption when I initiated this dissertation study was that there should be a strong boundary between the focal manufacturer and its users. In fact, this has been proven by showing the existence of a language difference at the user-manufacturer boundary. However, I also examined and proposed that there is a possibility of learning-by-interaction at the user-manufacturer level. I described this phenomenon as an oxymoron – a permeable boundary in chapter 1. It is a strong boundary but at the same time, I also observe the possibility of bridging this gap using current available technology.

I will support this argument through an example. During one of the joint product development projects, user John (pseudonym) exchanges emails with an engineer at the manufacturing company (Table 6.1). What I observe in this dialogue is that the user and the manufacturer are heavily involved in the joint problem-solving on how the enclosure became wobbly. The negative outcome of the product triggered this series of conversations. Even though the joint problem-solving is mainly done via email communication, the user even sends the video of the actual product used in the context of use. At the end of this problem-solving, the user figures out that the problem was due to the use of wrong screws. A more surprising fact is that this entire thread of conversation happened in approximately one day (26 hours to be exact). The example I present here shows that the communication and collaboration between a manufacturer and its users are quite feasible with current available technology.

This study suggests that the traditional boundary of the firm should be extended towards the user side. Collaborating and communicating with users should be an

important part of organizational study since the activities and the processes – in this case, the product development process – of the firm is extending towards the user side. The fact that the user-manufacturer boundary is permeable and the user-manufacturer learning is possible supports this argument.

In chapter 4, I presented an early empirical evidence of the user-manufacturer level learning. Departing from traditional learning curve studies (e.g. Argote, Beckman, & Epple, 1990; Wright, 1936), I show the learning effect at the user-manufacturer level emphasizing the importance of learning at this level. I also show the prompt exchange of interdependent information as an important micro-mechanism of learning at this level. All these findings support the importance and feasibility of the user-manufacturer joint problem-solving. Since most innovation studies basically assume internal problem-solving, the result of this study should inform innovation literature that the joint problem-solving is another venue that innovation can be spurred.

The direct communication and collaboration with the users are not seen as an efficient mechanism from a task-oriented and an information processing perspective. However, this thesis suggests the opposite side of the story. Further studies should be carried out to examine the positive and the negative side of user-manufacturer collaboration. More design rationales could be drawn from these studies by finding the mechanisms in which the negative aspect is minimized while the positives of the learning effect and the innovative outcome are maximized.

Table 6.1 Conversations in the Email Exchanges During the Joint Product Development

Sent: Thursday, July 28, 2005 2:23 PM Subject: new prototype Christa, I received the new box. This time, both the cover and the chassis are fairly stable. But the cover/chassis assembly screw holes still do not match up properly. **When I screw all the screws in tight, the box becomes wobbly**. If I loosen one screw in particular, the box becomes flat again. Please advise. - John
On Fri, 29 Jul 2005 simone@protocase.com wrote: Hello John, Christa forwarded your e-mail to me and asked if I could respond to it. I **checked with the manufacturing manager** in regards to the assembly screw holes not lining up properly and when screwing the screws in tight the enclosure becoming wobbly and he and the assembler **don't recall there was a problem with the enclosure**. Is it possible for you to take some pictures and e-mail them to me so I can show it to the manufacturing manager? I look forward to your response. Best Regards, Simone
Sent: July 29, 2005 12:22 PM Subject: RE: new prototype **Here's a video.** **I suspect it's b/c the holes don't quite line up perfectly.** Thus when I tighten the screws, the cover/chassis begins to bend b/c of the counter sink wedge effect. - John
---------- ***6 more messages were exchanged*** ----------
Received at: 29/07/2005 4:13:45 PM ---------- Ok. It might be an issue with the screws. As I recall, you don't stock any 100 degree screws so the plant used 82 degree screws for shipping. It could be that **the 100 degree screws go in further** (since it's a 100 degree countersink) and reveal the problem more so than the 82 degree screws. The warping becomes more pronounced as I tighten the screws. If I loosen one of the screws, it will flatten out. Christa didn't feel there was any problem with the hole positioning. I'm just going to defer to her on that. File this away under "it would be nice to fix but not a deal breaker." Still satisfied with the overall product. - John

6.3. Limitations and Direction for Future Research

I acknowledge several limitations and opportunities for future research in this thesis. The study shown in chapter 4 investigated project data for 359 user-manufacturer co-development projects. The research design in this study allowed me to identify the learning that happens between a manufacturer and its 359 communication channels with its customers. But these projects related only to one focal manufacturer. To gain external validity for this study's results, more firms and their interfaces with product or service users should be examined. By selecting field study sites carefully, different micro mechanisms of learning-by-interaction with users can be further identified as well.

While the two learning-by-interaction models in chapter 4 used the design and lead time as dependent variables, different types of dependent variables could be used in future studies to analyze further effects of learning. For example, the implications of learning on product innovation could be measured. Since users are known for their ability to provide functionally novel product features or solutions, measures of product innovation might be useful to understand how learning-by-interaction can affect the overall innovativeness of a product.

A specific mechanism of learning-by-interaction — timeliness of responding with interdependent information — was examined and found to be significantly associated with the learning outcome. However, this measure is an absolute term with the number of unresponded-to-design changes. A more detailed measure of exactly how long it takes a manufacturer to respond to design changes might be helpful to examine the issue more thoroughly.

In this study, only the initial state of learning could be investigated using the user company dummy variables. The question of whether the learning rate differs across different users can be investigated using the interaction term between experience and user company dummies. The dataset in this study did not have enough freedom to investigate this issue. But further data gathering could make this additional investigation possible. By tapping into the differences in the learning rate, more specific description of user-manufacturer joint problem-solving will be possible.

Future studies that examine the detailed mechanism of learning-by-interaction at the firm's boundaries should be interesting. Studies on learning and knowledge transfers on the supplier's side have been conducted (e.g. Lorenzoni & Lipparini, 1999), but learning on the user's side is seldom explored in such literature. Additional studies on this topic could relate the concept of learning-by-interacting to the firm's dynamic capabilities and highlight its importance.

Another future research subject could be about entrepreneurship research by focusing on technically-oriented firms' engineering problem-solving in the early development stage. The local learning process between users and a manufacturer is critical to understand the entrepreneurial process since it opens up the possibility of identifying and realizing new opportunities. In this regard, working with customers in the early problem-solving stage is one of the critical processes that require the entrepreneurs' careful attention and management. Technically-oriented firms often develop their first version of products by working with early customers. At this stage, a large portion of the critical design-related engineering decisions are made. They can have long-lasting effects on further development and improvements of the products as well as the organizational

structure that supports the product architecture. For service-oriented firms, the local learning process during the service often contributes to the improvement of services and the productization of services as we observe in the finance, consulting, and IT services industries. Therefore, it will be very interesting to further explore the phenomena studied in this thesis in the entrepreneurial firm setting.

References

Argote, L., Beckman, S. L., & Epple, D. 1990. The Persistence and Transfer of Learning in Industrial Settings. ***Management Science***, 36(2): 140-154.

Lorenzoni, G. & Lipparini, A. 1999. The Leveraging of Interfirm Relationships as a Distinctive Organizational Capability: A Longitudinal Study. ***Strategic Management Journal***, 20(4): 317-338.

Wright, T. P. 1936. Factors Affecting the Costs of Airplanes. ***Journal of Aeronautical Science***, 3: 122-128.