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Journal Article



N.B.: When citing this work, cite the original article.

Original Publication:

Mohammad H. Eslami and Nicolette Lakemond, Knowledge integration with customers in collaborative product development projects, *Journal of business & industrial marketing*, 2016, 31(7), pp.889-900.

<http://dx.doi.org/10.1108/JBIM-05-2014-0099>

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Postprint available at: Linköping University Electronic Press

<http://urn.kb.se/resolve?urn=urn:nbn:se:liu:diva-130858>

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Purpose

This paper addresses the need for managerial and organizational approaches to knowledge integration with customers in collaborative product development projects. The purpose is to identify the roles of customers in terms of the customer's knowledge contribution and timing of customer collaboration in the product development process.

Design/methodology/approach

This study is based on a multi-case study approach, comprising four product development projects from two large international suppliers. The cases were selected following the theoretical replication logic. Data consist of interviews, workshops, and secondary information. For each of the cases, a within case analysis was performed followed by a cross-case analysis.

Findings

The study shows that the customer's knowledge contribution is aligned with the specific requirements of each phase of the product development. Three specific customer roles are identified and connected to the customer's knowledge contribution and the timing of customer collaboration. The technical capability of the customer and the locus of initiative of the product development project are affecting the prerequisites for knowledge integration with customers.

Research limitations/implications

The study is performed from the perspective of supplier firms. The authors have not been able to capture the perspective of the customer in detail. As it is expected that both customers and suppliers benefit from a systematic knowledge exchange, future studies could examine knowledge contributions in both directions.

Practical implications

The findings can be used to devise effective approaches for collaborative product development with customers related to the customer's knowledge contribution and the timing of customer collaboration and provide guidance to firms seeking to benefit from knowledge residing at customers.

Originality/value

This is one of the first studies to focus on the integration of customers' knowledge in product development processes. This paper contributes to the customer-supplier collaboration literature by presenting further insight into customers' knowledge contributions, the timing of customer collaboration in product development processes and the prerequisites for knowledge integration with customers.

Keywords: customer–supplier collaboration; knowledge integration; new product development; customer’s technical knowledge; locus of initiative

1. Introduction

As knowledge has come to be regarded as a proprietary competitive advantage, companies need to consider strategies to update their knowledge bases and bring innovation to their products (Huang, 2010). Changes in market demand occur rapidly, and product technologies increase in complexity; therefore, firms must find and use external knowledge in their internal knowledge creation processes (Grant and Baden-Fuller, 2004). This requires knowledge integration across the boundaries of the firm (Johansson *et al.*, 2011).

Studies in the field of customer–supplier collaboration have focused on the effects of collaboration between suppliers and customers in new product development (NPD). These studies have found that suppliers as well as customers are important sources of knowledge (e.g., Enkel *et al.*, 2009; Un *et al.*, 2010). In fact, the possibility of product innovation increases if the supplier and customer exchange knowledge (Noordhoff *et al.*, 2011). A vast body of literature has advocated for the supplier’s involvement in NPD by allowing the supplier to provide input and contribute to decisions regarding the purchases used in manufacturing processes (e.g., Handfield *et al.*, 1999; Ragatz *et al.*, 2002; Petersen *et al.*, 2003; Cousins *et al.*, 2011). Furthermore, intense discussions have centred on the advantages related to the cost and innovativeness of a collaborative relationship, as well as the challenges of managing such a relationship effectively (Johnsen, 2009; Rosell and Lakemond, 2012). Another body of literature has emphasized the importance of input by the customer, henceforth referred to as the customer’s knowledge as this study is performed in the context of collaborative customer–supplier relationships (Day, 2000; Campbell, 2003; Lin and Huang, 2013). Firms that proactively use this knowledge in order to foster and enhance long-term relationships can create a significant competitive advantage (Campbell, 2003; Jayachandran *et al.*, 2005; Salojärvi *et al.*, 2013). Indeed, several studies regarding the role of the customer in NPD have revealed the importance of the customer’s knowledge in collaborative product development (Fang *et al.*, 2008; Athaide and Klink, 2009; Fuchs and Schreier, 2011).

Previous research has investigated the roles of the customer in the supplier’s product development process (Fang *et al.*, 2008). Nonetheless, the field lacks a comprehensive understanding of knowledge integration with customers in terms of what knowledge is integrated and the timing of this integration. Therefore, this paper intends to closely analyze the integration of the knowledge of the customer in the product development process of the supplier. Specifically, it will identify the customer’s knowledge contribution and timing of customer collaboration in collaborative product development. The paper is organized as follows: First, we will present an overview of relevant literature in the field. Then, we will describe the methodology and case

studies. After that, we will use the findings from the case studies to determine a conceptual model. Finally, we will present the theoretical and managerial implications, along with limitations and areas for future research.

2. Knowledge integration in collaborative product development

2.1 Collaborative product development and knowledge integration

The market demand for innovative products has put a greater pressure on firms to develop new products as well as increased the complexity of internal and external integration during product development. Collaborative product development has been addressed in several studies on customer-supplier relationships. These studies stress aspects as reducing development time, increasing the quality of products and diminishing product as well as development costs (Johnsen, 2009). According to the Product Development Management Association (PDMA) (1996), collaborative product development is defined as a collaboration of two or more companies as mutual partners in product development, aiming at delivering a final solution to the end user. This implies that the supplier as well as its customers may perform activities in close interaction in several phases of a new product development process (Anderson, and Narus, 1990).

Previous studies have shown that collaborative product development is dependent upon exchanging information and knowledge (Bengtsson *et al.*, 2013; Rosell *et al.*, 2014). In collaborative product development, knowledge needs to be captured from external actors as well as be integrated internally among the different functions of the firm (Bengtsson *et al.*, 2015). Consequently, in line with the knowledge-based view of the firm, knowledge is considered as the most important resources to create competitive advantage in the market. Typically, knowledge resides at the individual level and is highly dispersed. Hayek (1945, p. 519) describes this as “[...] knowledge [...] never exists in concentrated or integrated form, but solely as the dispersed bits of incomplete and frequently contradictory knowledge which all the separate individuals possess.” Consequently, the creation of new knowledge often requires a search for knowledge beyond the firm’s own boundaries, through inter-organizational collaboration (Huang and Chu, 2010; Zanini and Musante, 2013). Consequently, “the primary role of the firm [...] is the integration of knowledge” (Grant, 1996, p. 375). Here, the notion of knowledge and the integration of knowledge can be clarified by distinguishing knowledge from information. Information can merely be considered as a flow of messages, and is of course a necessary medium for knowledge to be created (Nonaka, 1994). In contrast to information, knowledge is anchored on the commitments and beliefs of its holders and guides the actions of these individuals. In some situations, the input of a customer may merely represent information rather than knowledge. As we are mostly interested in the actions that are performed in knowledge integration processes, we mainly use the term knowledge in this paper. Knowledge integration has been defined as the combination of specialized and

complementary knowledge (Tell, 2011). It refers to two processes: 1) gathering all different pieces of knowledge that are required for developing products, systems, solutions; and 2) creating new knowledge for a successful integration (Berggren *et al.*, 2011).

In the context of inter-organizational relationships in general, and customer–supplier collaborations in particular, firms can gain knowledge through knowledge transfer (Beecham and Cordey-Hayes, 1998; Simonin, 1999; Kotabe *et al.*, 2003; Squire *et al.*, 2009). Knowledge transfer typically refers to a one-dimensional flow between two actors (Szulanski, 2000; Berggren *et al.*, 2011). Similarly, knowledge sharing can be central in gaining access to external knowledge bases (Wu and Lin, 2013; Yen and Huang, 2013). In contrast to knowledge transfer, knowledge sharing implies revealing relevant knowledge without transmitting it in its entirety (Tiwana and McLean, 2005). Both knowledge transfer and knowledge sharing can be relevant for knowledge integration, but they refer to narrower concepts, as they do not consider the further process of combining different knowledge bases and creating new knowledge (Wijnhoven, 1998; Berggren *et al.*, 2011). Extending this notion to collaborative product development in a customer–supplier context implies that external knowledge bases need to be accessed as well as shared and combined and that new knowledge needs to be created. For instance, the components or subassembly systems that a supplier provides to a customer usually need to fit with other parts of a product. Therefore, in its extreme form, knowledge integration in customer–supplier collaborations refers to a reciprocal learning process. Okhuysen and Eisenhardt (2002, P. 384) have described this process: Knowledge integration is not simply a matter of assembling discrete pieces of knowledge, like Lego blocks, as the “knowledge as a resource” view implies. Rather, knowledge integration is the outcome of the process, “which consists of both the shared knowledge of individuals and the combined knowledge that emerges from their interactions”. (Okhuysen and Eisenhardt, 2002). Consequently, knowledge integration can be described as a process that is highly socially embedded, requiring interactive dialogues among individuals (Huang and Chu, 2010; Wu and Lin, 2013). This interaction is especially important when the integration of tacit knowledge is required. Compared to explicit knowledge, which can more easily be expressed, tacit knowledge demands platforms and procedures that invoke dialogue, such as knowledge-sharing routines (Vázquez-Casielles *et al.*, 2013; Wu and Lin, 2013). Consequently, explicit and tacit knowledge may require different approaches to knowledge integration (Nonaka, 1994; Grant, 1996).

2.2 The customer’s knowledge contribution and timing of customer collaboration

While knowledge integration processes have been described in some detail, little is known about the customer’s knowledge contribution and the timing of customer collaboration in collaborative product development processes. In this paper, the customer’s knowledge is defined as the technical knowledge that resides in the customer’s organization. The customer’s knowledge contribution is connected to the

input of the customer to the collaborative product development project. The customer's knowledge is necessary to overcome the technical challenges that might arise during the product development project (Peled and Devir, 2012), and is an important rationale for knowledge integration. To our knowledge, no detailed studies show a systematic overview of knowledge contributions of customers. The customer's knowledge needs to be clearly distinguished from customer knowledge. Previous studies have stressed the importance of customer knowledge, which in contrast to the customer's knowledge refers to a supplier's internal competence to generate and integrate knowledge about customers (see e.g. Campbell, 2003).

The timing of customer collaboration in the product development process is related to the stages of the product development process. Throughout these stages, the specific innovation problems that need to be resolved vary (Cooper, 2008; Gronlund et al., 2010). In customer-supplier relationships, the contributions and responsibilities of each partner, as well as the associated risks, are related to the specific stage in the product development process. However, previous studies have only focused on the relationship between timing and supplier roles (Kamath and Liker, 1994; Wynstra et al., 2001; Zsidisin and Smith, 2005). In order to address this shortcoming, this paper addresses the timing of customer collaboration. We consider the idea, development and testing phase following the idea of a stage gate system (Cooper, 2008; Cooper and Edgett, 2012). Although these phases by no means imply a strictly sequential process, they represent important phases in which information is gathered and knowledge is integrated followed by management decisions to continue to invest in the project or not (Cooper, 2008). The early stages of product development projects are usually more precompetitive, while the later development and testing phases involve a higher degree of competitive pressure and negotiations. In addition, during the early stages of product development processes, the interaction between firms and their customers tends to primarily focus on differences in knowledge and skills stemming from creative ideas, while in the later phases it is possible to leverage the common ground that has evolved (Srikanth and Puranam, 2011). Consequently, by determining the customer's knowledge contribution and the timing of customer collaboration, more insight can be gained into how firms can integrate their customer's knowledge in collaborative product development processes.

Previous studies have examined the role of customers in collaborative product development activities (e.g., Blazevic and Lievens, 2008; Coviello and Joseph, 2012; Fang *et al.*, 2008; Kaulio, 1998; Nambisan, 2002; Aarikka-Stenroos and Jaakkola, 2012). These roles are providing some insight into to the customer's knowledge contribution and timing of customer collaboration. As a first role, the customer can be considered as a resource, i.e., one who acts only as an information resource of new product ideas (Coviello and Joseph, 2012; Fang *et al.*, 2008). The customer as a resource provides a minor contribution to the product development process, mostly by sharing relevant information about their needs and business characteristics. The customer might be unaware of the details about the development process at the

supplier. This implies that the customer does not have a dominant role in the knowledge integration process. Second, the customer can be a co-creator of new products (Nambisan, 2002). This implies that both the customer and the supplier are interacting as active partners (Huang and Chu, 2010; Wu and Lin, 2013). In this type of relationship, the customer is recognized as an important source of knowledge and the employees from the customer are highly involved into the supplier's problem-solving logic and process (Rosell and Lakemond, 2012). This problem-solving process includes activities such as diagnosing needs, designing and producing solutions, system engineering, managing value conflicts and solution implementation (Aarikka-Stenroos and Jaakkola, 2012; Peled and Devir, 2012). The role of the customer as a co-creator is particularly prevalent in the development of industrial products, as these products tend to require complementary knowledge from the customer (Blazevic and Lievens, 2008; Fang *et al.*, 2008). Third, the customer could play the role of a user, in which it participates in product testing and support (Nambisan, 2002). Lagrosen (2005) refers to this relationship as facilitative, i.e., both parties are willing to invest in common activities and resource ties to increase the cost benefits of the relationship. This collaboration allows the customer to share feedback with the supplier and make suggestions for improvement (Blazevic and Lievens, 2008). For instance, when a potential customer is involved in the testing phase it increases a firm's product launching capabilities and contributes positively to product development success (Kandemir *et al.*, 2006). In summary, the different roles of the customer provide some insights into the customer's knowledge contribution and timing of customer collaboration. Table 1 provides an overview of the customer's different roles and the characteristics connected to these roles that are expected based on the literature.

Table 1. Roles of the customer and implications for knowledge integration

Characteristic	Customers as co-creator	Customers as user	Customers as resource
Focus	Technological solutions	Product experiences	Product ideas, functionality
Timing	Throughout product development process	Late phase of product development process	Early phase of product development process

3. Methodology

3.1 Research design

In order to study knowledge integration in collaborative product development, we adopted a multiple-case-study approach to investigate the phenomenon in its natural setting and develop an understanding related of timing and content of knowledge integration with customers (Meredith, 1998). The multiple-case study builds on an investigation of two large suppliers and several of their customer relationships in four

product development projects, thereby allowing us to investigate variations among different projects (Dubois and Gadde, 2002). Case studies were considered an appropriate approach, as our aim was to develop an in-depth and detailed understanding of the role of customer's knowledge and collaboration in the product development process. This approach was deemed suitable, as it allowed us to study the rather complex phenomenon that collaborative product development with customers represents in its real-life context, following the theoretical replication logic (Yin, 2009).

In order to eliminate the possibility that the results only can be explained by a lack of innovative capabilities of the supplier, which have been found to significantly determine customer-supplier collaboration success (Oh and Rhee, 2010; Wynstra *et al.*, 2010), we selected two large international suppliers. In order to ensure anonymity, we refer to these firms as ROLIND and MEDCOM. Both firms are market leaders within their fields, have a long history of innovation and are well known for their internal R&D capabilities. ROLIND has approximately 50,000 employees around the world, an annual R&D expenditure of approximately 3%, and a patent portfolio that increases by approximately two patents per day. ROLIND develops and manufactures products based on several technology platforms; its customers are affiliated with the automotive, mechanical engineering, and aerospace industries. MEDCOM has almost 49,000 employees in more than 130 countries. With an annual R&D expenditure of approximately 3%, MEDCOM is part of Thompson Reuters' top-100 list of the most innovative firms. MEDCOM provides various technologies in areas such as construction, material technology, mining, and machining solutions.

Although both suppliers are capable of performing internal product development, they engage actively in collaborations with their customers. We studied two product development projects at each company. The cases were selected together with strategic managers at the firms. The four cases were deliberately chosen to represent complex product development in terms of the technical requirements and originality of the projects. Each of the four projects can be considered as knowledge intensive and rely on the integration of several knowledge bases. In addition, the cases were selected to represent different levels of customer commitment in the projects and varying customer contributions. As such, we used the theoretical replication logic for selecting our cases with the purpose of demonstrating contrasting results (Yin, 2009). Table 2 provides an overview of the four projects.

Table 2. Characteristics of the four cases

Company (supplier)	Focus of project	Customer	Example of knowledge bases required	Size of project (FTE)	Commitment of customer
ROLIND / Solar	Complex industrial system consisting of a number of components for a product called Tracker	Customer A	Mechanical engineering, electrical engineering, mechatronics	8-10	High
ROLIND / Mono	Complex industrial system solution with a number of subsystems for steel production industry.	Customer B	Mechanical engineering, chemical engineering, mechatronics, machine design, metallurgy and lubrication technology	10-12	Medium
MEDCOM / Implant	New implants in medical applications	Customer C	Medical application, biomedical engineering and material science	8-10	Medium
MEDCOM / Fra	New cobalt chrome material for medical applications	Customer D	Material science, process engineering, biomedical engineering	4-6	Low

3.2 Data collection

For each project, collaboration with one customer was considered. The companies allowed us to interview different key informants in each development project. Further, we gathered secondary information about each company and project. During a two-year study, one of the authors visited both supplier companies on several occasions and collected primary and secondary data in order to allow for data triangulation and to improve construct validity (Gibbert *et al.*, 2008). The primary source of data at ROLIND and MEDCOM includes 25 in-depth, face-to-face interviews with key informants, i.e., development managers, development engineers, technical managers, project managers, sales managers, sales application engineers, and portfolio managers. The interviews, lasting between one and three hours, were based on a semi-structured approach whereby a list of predetermined areas provided guidance for asking further questions depending on the responses of the interviewees (Beverland and Lindgreen, 2010). The interviews were recorded and later transcribed and coded. A brief overview of the data is presented in Table 3.

Table 3. Overview of interviews and workshops

Company	Case	Number of interviews	Time period
ROLIND	Solar	<ul style="list-style-type: none"> 6 Interviews (10 hours) with project manager, development engineers, sales manager, technical manager 2 Informal meetings (2 hours) with 2 respondents 	July 2012 – December 2013
	Mono	<ul style="list-style-type: none"> 10 Interviews (16,5 hours) with project manager, development manager, development engineers, sales manager, sales engineer, technical manager, production manager 3 Informal meetings (4 hours) with 3 respondents 	
	Solar and Mono	<ul style="list-style-type: none"> 1 meeting (2 hours) with 6 participants 1 Workshop (4 hours) with 8 participants 	
MEDCOM	Implant	<ul style="list-style-type: none"> 5 Interviews (9 hours) with project manager, development engineer, R&D manager, sales strategy manager and product manager 1 Informal meeting (1 hour) with 1 respondent 	July 2012 – March 2013
	Fra	<ul style="list-style-type: none"> 4 Interviews (6,5 hours) with project manager, development manager, sales manager and product manager 	
	Implant and Fra	1 meeting (2 hours) with 2 participants	

Moreover, the visits of the researcher to ROLIND and MEDCOM involved numerous informal discussions, which helped to provide additional information about several facets: the context of the project, overall strategy, nature of their collaboration with the customers, and internal integration. The informal discussions also allowed us to confirm our findings from one perspective with those of another (Eisenhardt and Graebner, 2007). The researcher continuously documented the findings and reflections based on the informal discussions. Complementary data was also gathered during separate workshops and meetings with project managers at ROLIND and MEDCOM. At the end of the study, different participants were involved and participated in a workshop, and a final report was distributed before the workshop at each company. To sum up, we have purposively included different functional perspectives, gathered and updated data during an extensive period of time, and used complementary data sources such as interviews, informal discussions, workshops and secondary material.

One of the limitations of this study is that it adopts predominantly the perspective of

the supplier firm. In order to access the viewpoints of the customer firms as well, for each case, we have gathered valuable documents and reports from the customer. This allowed us to triangulate the available data across various data sources in order to identify patterns (Gibbert *et al.*, 2008).

3.3 Data analysis

For each of the four cases, in line with recommendations about performing case study research (Yin, 2009), a complete case description was written. These case descriptions were based on our readings of the transcripts, secondary documents, our own interpretations from the informal discussions and workshops and other relevant literature sources. The data analysis was based on a content categorization of the interview data using a predetermined coding scheme, which was carefully aligned with the theoretical framework. The predetermined categories, e.g., *customer's knowledge contribution*, and *timing of customer collaboration*, were derived from the theoretical framework. It is important to note that we did not follow an inductive approach, but rather started with our general theoretical framework, which allowed new codes to be added and redundant ones to be deleted. To confirm the internal validity, we performed pattern matching by comparing the predicted and empirical patterns (Yin, 2009). Moreover, our investigation of the empirical results led to the emergence of new themes. Initially, the aim was to connect the customer's knowledge contribution to the timing of customer collaboration in the product development process. During the analysis, additional factors, such as customer's level of *technical capability* and *locus of initiative*, were identified when we ascertained the customer's knowledge contribution and timing of customer collaboration in relation to the associated customer roles. Consequently, by noting the similarities and differences, we could perform a comparative case study. To determine if our findings were valid, four case study reports were written and presented to all participants, whose feedback was sought and subsequently analyzed (Gibbert *et al.*, 2008). We used the principle of chain of evidence (Yin, 2009) when presenting the initial findings at the workshop. This provided the participants with an opportunity to review the study, comment upon it, and discuss their understanding of it. Consequently, these systematic discussions enhanced the validity of our research (Miles and Huberman, 1994).

4. Case studies

This section consists of a brief description of the four projects and the collaboration with different customers.

4.1 Solar project

The Solar project resided at the firm ROLIND and focused on the development of a subsystem for a product referred to as Tracker. The Tracker product targets the increasing market of solar energy production and is marketed by potential customers

of ROLIND. Although ROLIND had relatively little experience in this market, the subsystem could potentially enhance the performance of previous generations of the Tracker product. Consequently, ROLIND expected that their subsystem would yield a high demand in the future. The development process started with an internal idea evaluation and a search for relevant customers for this project. During the ideation phase, Customer A was selected and involved in the development of the product. Customer A has extensive technological knowledge relevant to the Solar project.

During the ideation phase, ROLIND and Customer A discussed various aspects of the specifications, including certain characteristics of the system's components and expected performance.

“At the beginning, we needed to understand more about their previous issues. Thus, during discussions, our customer described the failure modes and challenges that they had faced with the previous component.”

Sales application engineer, ROLIND

Customer A thus provided important operating knowledge about the product in use. ROLIND could use this specific knowledge about the product in Customer A's final product to optimize the solution and effectiveness of the system. However, Customer A's commitment to the project was rather low and the customer did not seem to be interested to contribute a lot to the project. Therefore, ROLIND was eager to show that it could develop a new system that addressed all previous concerns of the customer. As a consequence, ROLIND avoided delivering the prototype to Customer A before it had at least partially validated the technical solutions at their own premises.

“During the development phase, we did not deliver the initial prototype to our customer, because we were unsure whether the prototype was robust enough at that time. Moreover, our customer did not seem motivated to contribute with any ideas during the development phase, especially before verifying the solution's effectiveness.”

Sales Manager, ROLIND

First, ROLIND performed several internal tests on the product internally. When ROLIND felt comfortable with the results of the internal tests, they sent the later prototype to the Customer A and asked them to conduct some initial testing of the prototype in their final product. Upon completion of these tests, Customer A and ROLIND shared their understanding about the results of the prototype tests.

“We have shared our analysis and interpretation of the test results carefully in order to determine the system performance. We also discussed technical issues that had arisen during those tests, which affected speed load and current consumption.”

Development Engineer, ROLIND

Thus, ROLIND and customer A performed some evaluations and some further problem-solving on the test results. This helped ROLIND to make several additional adjustments to the system in order to improve its performance.

4.2 Mono project

At the same firm, ROLIND, the Mono system was developed. This is a system solution for heavy production equipment used in steel production. The Mono system is highly complex, as it builds on the integration of a number of technical subsystems. It is continuously exposed to extremely heavy loads and the harsh environment of steel production. The project was developed at the customer's request. Customer B selected ROLIND based on ROLIND's initial proposal that was assessed in competition with alternative proposals from other suppliers. Customer B contributed to the project by supplying important knowledge about the operational environment of the system.

At the outset, ROLIND was focused on clarifying the expectations of the customer. Numerous technical requirements were shared between Customer B and ROLIND. The initial performance calculations by ROLIND created some concerns for the customer and resulted in deep discussions about the product concept. In addition, the possible failures during operation were discussed. The development engineers from both firms proposed and discussed several alternative solutions. During these discussions, ROLIND gained further understanding of the requirements of the system.

“I would definitely say that we needed to calculate the value and operational performance at the customer's site and that is what we did. When we were there, we would typically go with the customer through all the Excel files, where they categorized different systems on the machine and classified failure types, along with the follow up. We converted this information into raw data, which enabled us to estimate the service life. They definitely helped us to do it.”

Development manager, ROLIND

Customer B did not only have considerable technical knowledge about the operational environment of the product, but the above quote seems to express some win-win situation. Two reasons for this emerge from our data. First, the two firms were dependent on each other and not only ROLIND but also Customer B had an important interest in the project. Consequently, both firms learned in the process and obtained a significant amount of knowledge. Second, through the interaction in the early phase, ROLIND could convince Customer B that the Mono project had much value for them.

During the development phase, the two firms formed a joint team that reviewed the design of the system regarding the functionality and interdependencies in the system.

“When we presented the overall system design to the customer, several issues and disagreements arose, as they had minor concerns about some of the dimensions and interfaces (...). We discussed their suggestions for addressing the problems with the interfaces, which allowed us to recalculate the operational performance and redesign the Mono system.”

Project Manager, ROLIND

Thus, the customer’s knowledge contribution was not only based on a review of the product design or prototype. Rather, the customer provided several alternative ideas in order to better fit the design to its own production equipment.

Further integration of the two firms occurred during the testing phase. Together, the firms addressed some problems during the testing of the system.

(During testing,) “It was very important for both parties to understand what the issues were. For instance, when we saw the breaking of some of the standard components, we told them, ‘Ok let’s take out the system and analyze it together. Together with customer, we examined each of its components and performed in-depth investigations. We chose this approach, as we believed that it would help us change their mind regarding our solution.”

Development engineer, ROLIND

Therefore the focus of knowledge integration was on evaluating issues such as failure mode and breaking point. The issues were solved directly on site, while others required further analysis and were addressed and solved together in subsequent meetings.

4.3 Implant project

The Implant project was performed at the firm MEDCOM and focused specifically on the development of a new material that matches the requirements for implantation in the human body. The project was a response to the high demand for reliable performance of this material in a wide range of medical applications. The project was requested by a specific customer, Customer C, which contacted MEDCOM. The Implant project was quite complicated, since different knowledge bases were required in the development process. Customer C was the only customer involved in the development of the Implant project. The customer had some knowledge of

mechanical testing and actual machining of the new material. However, Customer C's knowledge of the potential development of the material was rather limited.

In the ideation phase, Customer C and MEDCOM met in order to discuss the specifications of the new material. They shared their concerns related to different biocompatibility and surface properties of the implant material.

“As our customer's knowledge of the material development was limited, we were mainly keen to involve them in the testing phase. In addition, we shared the internal test results, which we reviewed together.”

Sales application engineer, MEDCOM

In addition to some internal test, Customer C performed some specific fatigue tests on Implant to understand the strength of the material based on the application of the material. They shared the result of the fatigue tests with MEDCOM and they discussed the possibilities of improving the material. The discussion touched on how they need to develop the material by adjusting certain elements.

“After customer representatives shared their concerns, we felt that their viewpoint was relevant and interesting. In return, we shared the reasoning behind our choices (...). Together with the customer, we established the robust parameters the material required, and agreed to adjust certain elements.”

Development manager, MEDCOM

Another technical dialogue with Customer C was related to manufacturing technology related to the production environment of Customer C. More specifically, knowledge was integrated about the implications of high temperatures in production and the consequences for processing the materials on the production equipment.

“During testing, our engineers were the ones in direct and most frequent contact with them. From my point of view, our engineers work with the material development and need to go to the production plant [at Customer C] and have physical contact with the manufacturing process.”

Development engineer, MEDCOM

Thus, the development manager of MEDCOM stressed that these visits helped them to understand the consequences of the production environment of the customer in which MEDCOM's product needed to be further processed. Customer C contributed with its knowledge by explaining its production process to MEDCOM engineers, but also indirectly by letting MEDCOM's engineers observe and experience the production process.

4.4 Fra project

The Fra project focused on the development of new material based on cobalt chrome. This material is like the implants in the Implant project also used in several medical applications. The project originated from the internal corporate R&D of MEDCOM. During the pre-study phase, MEDCOM initiated a contact with Customer D. Customer D is new in the market, but extremely eager to increase its market shares.

Knowledge integration with Customer D was limited to the ideation phase of the project. In this phase, MEDCOM received information about the technical requirements and specifications from Customer D. The main interaction revolved around MEDCOM's solution for the new material and the expectations of Customer D.

“At the beginning of the project, we needed to discuss and exchange ideas about the material surface properties. The aim was to gain the necessary knowledge on the feasibility of machining, casting and forging of the material.”

Sales manager, MEDCOM

In other words, MEDCOM needed to understand how the new material was going to be used in Customer D's production process. However, Customer D had still little experience with this type of product, and therefore, limited knowledge about the application of the material. As a consequence, MEDCOM did not actively involve the customer in the subsequent phases of the project.

“Although our customer needed our new material, due to their lack of knowledge about the technical aspects, their contribution was limited to the beginning of the project only.”

Project Manager, MEDCOM

Table 4 summarizes the specific customer's knowledge contribution and timing of customer collaboration in the four cases.

Table 4. Customer's knowledge contribution and timing of customer involvement in the four cases

Project	Customer	Customer's knowledge contribution	Timing of customer collaboration
Solar (ROLIND)	Customer A	<ul style="list-style-type: none"> • Specifications and certain characteristics of the system's component • Sharing of the result of prototype test by customer • Discussing of problems related to the behaviour of the system. 	Ideation and test phases
Mono (ROLIND)	Customer B	<ul style="list-style-type: none"> • Technical requirements and failure mode analysis regarding the existing system • Value calculation and operational performance of the system • Feasibility evaluation of functionality and system interdependency • Analysis and evaluation of the failures and performance during testing and operation 	Ideation development and test phases
Implant (MEDCOM)	Customer C	<ul style="list-style-type: none"> • Specification of the material • Evaluating testing of material at supplier • Sharing of the result of fatigue test • Planning and analyzing the manufacturing process design 	Ideation and test phases
Fra (MEDCOM)	Customer D	<ul style="list-style-type: none"> • Technical specifications and requirements for the component 	Ideation phase

5. Case discussion —knowledge integration with customers

5.1 Customer's knowledge contribution and timing of customer collaboration

Previous studies have addressed the importance of the timing of collaboration in relation the role of the supplier (Kamath and Liker, 1994; Wynstra *et al.*, 2001; Zsidisin and Smith, 2005). Our study provides additional insights to the literature on customer-supplier relationships by addressing how the customer's knowledge contribution relates to the timing of collaboration. Furthermore, we also show how these knowledge contributions are different in each phase and relate to the role of the customer. In the Mono project, knowledge integration between the customer and the supplier was the most far-reaching. This was expressed both in terms of the customer's knowledge contribution that was extensive and focused on joint and interactive problem-solving, and the timing of customer collaboration which took place in each phase of the development process. The role of the customer in this project was in line with the idea of the customer acting as a co-designer (Nambisan, 2002). In the ideation phase, the knowledge integration was focused on clarifying the expectations of Customer B about the technical requirements. During these exchanges ROLIND gained a clear understanding of the requirements of the system. In the

development phase, engineers from ROLIND and Customer B reviewed the design and the customer provided suggestions. Throughout the product development process, the focus of customer B's knowledge contribution changed from expectations and demands to technical requirements, ideas for solutions, evaluation and validation of system performance, and optimization of the physical product. Consequently, Customer B's knowledge contribution was broad and included multiple aspects.

Knowledge integration with the customers in the other product development projects was not as far-reaching. For instance, in the Fra project, MEDCOM rarely interacted with Customer D. The customer only contributed in a minor way to the product development project and the timing of customer collaboration was confined to the project's ideation phase. Still, in this phase, it was important to capture the customer's knowledge in terms of requirements and specifications. These could be discussed and integrated (Lagrosen, 2005) and were important for the further development of the product.

Compared to the Mono project, which shows that knowledge integration is based on joint efforts in problem-solving (Huang and Chu, 2010), in the Solar project, the customer's activities occurred mainly in the early and late phases of the development project. The main customer's knowledge contribution was related to product specifications, evaluation of the optimization of the physical product, and refinements based on testing. In the Implant project, Customer C's limited technical knowledge about the product prevented a more extensive contribution during the development phase and collaboration was limited to the ideation and testing phases. The collaboration of customers during early phases and testing has been previously related to a facilitative customer-supplier relationship (Lagrosen, 2005). This enables suppliers to detect product flaws in the development cycle (Nambisan, 2002).

Consequently, our study shows that, during the initial phases of product development process, the input of the customer tends to focus on gaining an understanding of the requirements and creating ideas and commitment for a solution. In contrast to our expectation posed in Table 1, this seems to be even the case when the customer acts as a user. Especially in the ideation phase, suppliers are looking for deviating perspectives and different interpretations (Srikanth and Puranam, 2011). In later phases, when the defined concept is to be transformed into a physical product, the knowledge contribution by the customer could be more focused on synchronizing problem-solving activities pertaining to the evaluation, validation and optimization of the physical product. Therefore, this study's findings point at an alignment between the customer's knowledge contribution and the requirements of each phase of the product development process. The results also show how a more far-reaching role of the customer in terms of the customer's knowledge contribution indicates extensive collaboration in more phases. Based on these results, we formulate the following propositions:

Proposition 1: The customer's knowledge contribution is aligned with the specific requirements of each phase of the product development process

Proposition 2: A customer's knowledge contribution based on co-creation and joint problem-solving is related to continuous collaboration throughout the product development process

Proposition 3: Customers that act as users are involved in early phases to gain an understanding of the requirements and create commitment, and in later phases to validate solutions

Proposition 4: Customers that act as a resource are involved in early phases to gain an understanding of the requirements and create commitment

5.2 The customer's technical capability and locus of initiative

In addition to the above results, two factors emerge from the cases. These factors affect and constrain the customer's knowledge contribution and the timing of customer collaboration. First, the customer's level of technical capability, referring to the extent to which it understands the new product or system, influenced the prerequisites for the customer to contribute with knowledge. For instance, an important prerequisite for the extensive knowledge contribution of Customer B in the Mono project was that it had considerable technical knowledge that allowed the customer to validate the product's architectural choices and formulate design requests (cf. Peled and Devir, 2012). This finding is in line with several previous studies that have identified a relationship between the customer's knowledge and its contribution to the supplier's activities (Athaide and Klink, 2009; Smals and Smits, 2012). For instance, Athaide and Klink (2009) find that collaboration with customers with a high technical capability helps to mitigate environmental uncertainty and improve adaptation. Similarly, Smals and Smits (2012) report that collaboration with capable customers increases the likelihood that value will be jointly created. The case studies in this research reveal that a sufficient level of technical capability is required for successful knowledge integration with the supplier (cf. Brusoni *et al.*, 2001). A lack of technical capability influences not only the knowledge contribution by the customer, but also the timing of customer collaboration. For instance, in the Fra project, Customer D did not have the relevant technical knowledge to justify collaboration beyond the ideation phase, at least not according to the supplier. Similarly, in the Solar project, Customer C's technical capability was not perceived as sufficient to organize for a knowledge contribution during detailed product design, despite Customer C's learning intent. Consequently, we formulate the following proposition:

Proposition 5: The (lack of the) customer's technical capability constrains the customer's knowledge contribution and timing of customer collaboration

Second, the locus of initiative of the development effort also emerges as a factor influencing the customer's knowledge contribution and timing of customer collaboration. Some studies have found that the inclination of a customer to contribute with its knowledge positively influences the degree of knowledge integration (e.g., Huang and Chu, 2010; Smals and Smits, 2012). When the customer commits its resources and establishes a relationship driven by a learning intent, a relationship tends to be more integrative (Lagrosen, 2005). In the case studies in this paper, this commitment emerged from the locus of initiative. By taking the initiative for the project, the customer seemed to take a more active role and appeared more willing to integrate knowledge with the supplier. In contrast, in the Solar project, which was initiated by the supplier, ROLIND needed to put considerable effort into convincing Customer A about the value of the new product. Although Customer A was technically very capable and could have contributed with more knowledge also during the development phase, it was not inclined to put much effort into the project. Based on these findings we formulate the following proposition:

Proposition 6: The locus of initiative of the development effort constrains the customer's knowledge contribution and timing of customer collaboration

6. Conclusion

6.1 Theoretical implications

This paper aimed to provide a deeper insight into the integration of the customer's knowledge in collaborative product development process. Our findings contribute to the current knowledge on this issue and augment the existing literature by explaining how firms create value by accessing and integrating the knowledge of their customers (Grant and Baden-Fuller, 2004). The four case studies reveal that customers have different roles, and that these roles can be expressed in terms of the customer's knowledge contribution and timing of customer collaboration. Furthermore, we have proposed that two factors constrain the customer's knowledge contribution and timing of customer collaboration, i.e. the customer's technical capability and the locus of initiative. We have outlined the customer roles further in Table 5. While the customer as a co-creator has previously been described as a far-reaching relationship providing opportunities for knowledge integration (Nambisan, 2002; Lagrosen, 2005), the results of our study imply that the customer's level of technical capability as well as the locus of initiative for the project are two important prerequisites for a customer to be able to act as a co-creator. In other situations, we propose that the customer has a less prominent role and acts either as a user or a resource. The role of a user implies that either the locus of the initiative resides at the customer, something which indicates incentives for learning (Huang and Chu, 2010) or that the customer has a technical capability that is critical for the project. The customer as resource suggests that knowledge integration is based on a transactional relationship (Lagrosen, 2005),

that the collaboration is limited in time in the early phases, and the that customer's knowledge contribution mainly focuses on the product specifications. This situation may be prevalent when the locus of initiative resides at the supplier and when the customer is not perceived as technically capable.

Table 5. Roles of customer according to the knowledge content and timing of knowledge integration

Characteristics	Co-creator	User	Resource
Locus of Initiative	Customer	Customer	Supplier
Customer's technical knowledge	High	Low	High
Timing of Customer collaboration	Ideation, development and testing phase	Ideation and testing phase	Ideation phase
Customer's knowledge contribution	<ul style="list-style-type: none"> • Technical and specification requirements • Product feasibility, development challenges and issues • Product optimization and analysis of the test result 	<ul style="list-style-type: none"> • Technical requirements and specification • Product optimization and analysis of test result 	<ul style="list-style-type: none"> • Technical and specification requirements

The three distinct roles identified in this paper improve our insight into the different knowledge integration mechanisms underlying collaborative product development with customers. We demonstrate that the use of the knowledge based view as a theoretical lens (Grant, 1996) increases the understanding of customer collaboration as a knowledge integration challenge. The literature has not systematically examined the conditions when knowledge integration is beneficial. Previous studies have pointed at the importance of internal technical capability (Cui and Wu, 2015), but our study outlines the customer's technical capability and the locus of initiative as two additional factors. Our findings indicate that knowledge integration with customers has a significant impact on the organizational design of product development projects and requires a contingency approach (e.g Kieser and Kubicek, 1983). Although the results and propositions need to be validated further, this paper addresses the need for creating a better understanding of the strategic and management issues related to collaborative product development with customers (Greer and Lei, 2012).

6.2 Managerial implications

As customers are recognized more and more as important suppliers of knowledge in product development processes, firms face the challenge of devising effective approaches. Our findings provide some guidance for this. Suppliers that want to gain benefits from collaborative product development with customers need to be able to assess the conditions for knowledge integration as well as consider if they have

sufficient organizational support for implementing different collaboration approaches. More specifically, supplier firms need to systematically consider whether or not the customer has the right technical capability and assess the customer's motives and incentives to contribute with its knowledge. Furthermore, different collaboration approaches effect the organization of product development in different ways. In order to support knowledge integration with customers, specific managerial and organizational processes need to be devised in the each phase of the product development process. The three roles outlined in this paper and characterized by the customer's knowledge contribution and the timing of customer collaboration provide different lenses through which knowledge integration with customers can be viewed. All three are necessary for a more comprehensive understanding of knowledge integration in collaborative product development projects with customers and directed toward the creation of value for both the supplier and the customer.

6.3 Limitation and further research

This study has some limitations. As it builds on only four product development projects at two different firms, the possibility to generalize our findings is limited. Although our findings show a consistent pattern, studying a greater range of projects and cases might result in additional understanding. This may consider large-scale survey studies that can validate our results, but also additional case studies in other contexts. For instance, while we focused on projects conducted in large knowledge intensive firms, much can be learned from investigating smaller technology firms from other fields and sectors. Knowledge integration with customers in smaller technology firms may require intense collaboration, while the risks of knowledge leakage are high (Grandori, 2001). Another limitation is related to the phase-model used in our study. We have included ideation, development and testing as important phases in stage models of product development (e.g. Cooper, 2008). However, this study does not address launching and commercialization phases, which are also part of these models. Especially when developing complex products and systems, the interaction with customers during product launch is important for the success of the development project (Windahl and Lakemond, 2010; Ylimäki and Jukka Vesalainen, 2015). This warrants further research that focuses on knowledge integration with customers in the back-end phase of product development. An additional limitation is that our study adopts the perspective of the supplier. As usually both customers and suppliers benefit from a systematic knowledge exchange (Kotabe *et al.*, 2003), it would be interesting to integrate the perspectives of the customer and the supplier. However, this study has shed some light on collaborative product development with customers and will hopefully prompt further research in this area. Such investigations can provide additional insight into how the integration of knowledge with customers can be achieved in product development processes.

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Acknowledgment

The authors acknowledge financial support for this research from Vinnova and Ragnar Söderbergs Foundation. We thank the participating firms and the anonymous reviewers for valuable comments and feedback.