International Entrepreneurship and Management Journal (2019) 15:135–162
https://doi.org/10.1007/s11365-018-0550-3

Knowledge processing and ecosystem co-creation for process innovation: *Managing joint knowledge processing in process innovation projects*

David Sjödin[1]

Published online: 29 October 2018
© The Author(s) 2018

Abstract

Process innovation drives industrial competitiveness and sustainability but remains elusive since it requires co-creation and the sharing of idiosyncratic design knowledge in ecosystems of providers and customers of process equipment. This paper investigates how firms can manage knowledge processing through co-creation in joint process innovation projects. Analysis of cross-comparative case studies –including nine industrial ecosystem actors – identifies three types of technological challenge (complexity, novelty and customization) that creates knowledge-processing requirements (uncertainty, equivocality) during the value co-creation process. To manage these knowledge-processing requirements, this paper explains how three joint knowledge-processing strategies (joint problem solving, open communication and end-user involvement) help ecosystem partners make sense of the requirements and demands in process innovation. In this context, the procurement approach (such as contracting and relationship development) helps to facilitate higher levels of joint knowledge processing, drawing on the diverse knowledge of ecosystem actors to secure successful process-innovation outcomes. The present study contributes to the emerging literature on co-creation in process innovation by developing a framework that highlights the knowledge-processing dynamics in ecosystem relationships for process innovation. The implications for management extends to a practical tool that guides project managers in ensuring appropriate levels of joint knowledge processing among ecosystem actors.

Keywords Process innovation · Process Development · Networks · Open innovation · Value co-creation

✉ David Sjödin
david.sjodin@ltu.se

[1] Entreprenuership and Innovation, Luleå University of Technology, 97187 Luleå, Sweden

Introduction

Process innovation is a critical concern for companies seeking to encourage sustainable development and to enhance firm competitiveness (Pisano 1996; Terjesen and Patel 2017; Von Krogh et al. 2018). Process innovation is defined as the "*implementation of new or significantly improved production or delivery methods. This includes significant changes in techniques, equipment and/or software*" (OECD 2005, p.9). Successful process innovation can strengthen competitive advantage and sustainability through increased production volume, lower life-cycle costs, reduced environmental impacts, and improved production efficiency (Pisano 1996; Milewski et al. 2015; Schuman and Brent 2005). On the other hand, process innovation initiatives can be perilous for the financial soundness of firms since process innovation projects are often large, costly and plagued by budget overruns, delays, and quality problems that may cause significant disruption of the production process and possibly result in plant down time (Filippou and King 2011; Lager 2012; Rönnberg Sjödin et al. 2016). In the current era, the challenges as well as the opportunities continue to multiply as the wave of process innovation, flowing from the application of novel digital technologies (e.g. the Internet of Things), and the advances in artificial intelligence and automation, gathers pace (Iansiti & Lakhani 2014; Porter & Heppelmann 2014; Sjödin et al. 2018). For example, the complexity of implementing novel digitally enabled autonomous manufacturing systems within the established production infrastructure can involve great uncertainty for manufacturers and their ecosystem (Parida et al. 2018; Sjödin et al. 2018). Thus, the ability to proficiently manage the application of knowledge and skills in order to continuously innovate their production processes is a competitive necessity for many firms (Lager 2012; Skinner 1992; Terjesen and Patel 2017).

From a practical perspective, managing process innovation is especially challenging since it is rarely conducted solely within the boundaries of the firm but rather extends across ecosystems of equipment providers, customers and technological partners (Hutcheson et al. 1996; Rönnberg Sjödin et al. 2011). Indeed, firms are typically required to engage in co-creating new process solutions within an ecosystem of equipment providers since the knowledge and skills involved in designing, manufacturing and implementing their own process equipment lie outside their core competencies (Lager 2012; Bruch and Bellgran 2012). On the other hand, process innovation is deeply entrenched in internal operations, and equipment suppliers depend on gaining access to their customers' knowledge so that they can customize process solutions to their idiosyncratic design requirements (Robertson et al. 2012; Rönnberg Sjödin 2013). Therefore, joint process innovation projects entail significant challenges in gathering, processing, and recombining knowledge by customers and providers alike in the process of ecosystem co-creation. Yet, there is limited understanding of how firms devise knowledge-processing activities to develop process innovation (Keupp et al. 2012). Thus, there are several reasons for augmenting knowledge on how firms can manage value co-creation in open process innovation (Von Krogh et al. 2018; Robertson et al. 2012; Rönnberg Sjödin 2013).

First, this study conceptualized process innovation as a knowledge-intensive process focused on inter-organizational problem-solving activities that involve the creation and recombination of technological knowledge among ecosystem actors (Terjesen and Patel 2017; Milewski et al. 2015; Eriksson et al. 2016). This conceptualization contributes to

process innovation research by incorporating the explanatory perspectives of information processing and knowledge management (Tushman and Nadler 1978; Daft and Lengel 1986; Grant 1996; Zack 2001). Yet, prior studies in process innovation have rarely focused on the knowledge-processing challenges inherent in such endeavors. It, therefore, seems fruitful to study the causes and concerns arising from key knowledge-processing challenges and requirements in joint process-innovation projects among ecosystem actors, and how these can best be managed. For example, internally focused process-innovation research has found that uncertainty and equivocality pose significant challenges in the early stages of process innovation (Daft and Lengel 1986; Frishammar et al. 2011), but lack insights on managing these within ecosystems. Generating a better understanding of how to manage uncertainty, equivocality and knowledge processing in value co-creation among multiple ecosystem actors is a key requirement for process innovation (Eriksson et al. 2016). Despite this, in the emerging literature streams to date, little consideration has been given to the ecosystem co-creation requirements of process innovation from a relational knowledge-management perspective.

Second, managing process innovation represents an iterative co-creation process involving the reciprocal exchange of information and knowledge between customers and providers within the ecosystem (Grönroos and Voima 2013; Rönnerg Sjödin et al. 2011; Bruch and Bellgran 2012). Yet, most prior studies have approached process innovation from the firm's internal perspective (Terjesen and Patel 2017; Milewski et al. 2015; Kurkkio et al. 2011), thus failing to capture the interactive strategies adopted when managing challenges in knowledge processing among multiple actors (Eriksson et al. 2016; Stock and Tatikonda 2008; Rönnberg Sjödin et al. 2016) from both sides of the value co-creation process. In contrast, studying both sides of the ecosystem should enable a better understanding of how appropriate selection of response strategies can be facilitated during critical activities such as partner selection, negotiation, development, and implementation by simultaneously capturing the perspective of both the technology suppliers and the technology user (Milewski et al.; Robertson et al. 2012).

Third, in the field of entrepreneurship and innovation management, there is a need to treat process innovation as a distinct unit of analysis and generate detailed insights into the challenges in knowledge processing that companies face and the approaches they require to develop new processes (Becheikh et al. 2006; Lu & Botha 2006). Indeed, the processes of innovation and value co-creation may differ considerably between product and process innovation. For example, compared to product innovation, process innovation is more likely to be complex, challenging to implement, sourced externally, and composed of tacit knowledge that is systemic to the firm's knowledge base (Gopalakrishnan et al. 1999). Yet, only a tiny fraction of studies is focused on process innovation (Terjesen and Patel 2017; Milewski et al. 2015). Thus, there is a need to learn more about the processes of innovation and value co-creation by extending the focus into process innovation.

This study addresses these shortcomings by specifically capturing multi-actor perspectives on the challenges and strategies for value co-creation and outlining the knowledge processing processes among ecosystem actors. Accordingly, the purpose of this paper is to address the question of *how firms can manage knowledge processing for ecosystem co-creation in joint process innovation projects.* To this end, the current

study has undertaken multiple case studies from seven providers and two leading customers engaged in process innovation in ecosystems within the process and manufacturing industries.

The current research effort makes several contributions. First, this study proposes an emergent framework for managing joint innovation projects by highlighting the interdependence among knowledge-processing requirements and joint knowledge-processing activities throughout the value co-creation process. For this purpose, the perspective of technological challenges and the procurement approach are incorporated as inputs to value co-creation in the ecosystem. Second, a set of propositions and key questions for understanding the dynamics of knowledge processing in process innovation ecosystems is proposed. Third, this study contributes by adding the novel perspective of knowledge processing in order to understand what makes for the success in joint process innovation. Finally, this study offers significant practical contributions; the findings and the framework developed provide insights into the planning of value co-creation processes with ecosystem actors before work commences: with whom to collaborate, by what methods, and during which stages.

Literature overview

Process innovation challenges and outcomes

Process innovation can be described as a deliberate and systemic development related mainly to production objectives, implying the introduction of new elements (e.g. equipment) into the production process to create or improve methods of production (Kurkkio et al. 2011; Reichstein and Salter 2006).

A principal challenge in process innovation centers on its systemic nature (Gopalakrishnan et al. 1999), meaning that change in one part of the production system will affect several other sub-systems and processes. Thus, the development of new processes, unit operations or individual pieces of equipment can have broad ramifications even when the changes appear on the surface to be localized in their impact (Gopalakrishnan et al. 1999; Robertson et al. 2012). In particular, the production environment, and the equipment that interacts with it, contain a number of highly specific attributes that could potentially cause problems during actual operation (Barnett and Clark 1998; von Hippel and Tyre 1995). For example, modifications to one piece of equipment can affect the operation of other equipment by changing the volume and characteristics of input materials. Moreover, new equipment may lead to new duties and skill requirements for the operating personnel and changes in work processes (Gopalakrishnan et al. 1999; Lager 2012).

Process innovation is a highly challenging endeavor that may involve significant knowledge processing and will certainly require the adaptation of process technologies to fit the firm's current production systems (Robertson et al. 2012; Robertson et al. 2009). Indeed, such adaption creates vast challenges in sharing and integrating knowledge across functional and organizational boundaries to reduce the inherent uncertainty. Yet, the literature has devoted surprisingly little attention to how process innovation actually unfolds; a deeper understanding of how firms can manage process innovations would be desirable (Keupp et al. 2012).

Knowledge processing for value co-creation in joint process innovation

Today, value co-creation among customer and ecosystems of equipment providers plays an indispensable role in process innovation (Reichstein and Salter 2006; Robertson et al. 2012; Rönnberg Sjödin 2013). Equipment providers are sources of innovation in process technology that is subsequently adopted by their customers (Hutcheson et al. 1996; Reichstein and Salter 2006). In implementing novel technologies (i.e. innovation) successfully, co-creation of value is the underlying determinant that helps simultaneously to satisfy customer needs and to produce benefit for the provider (Edvardsson et al. 2011). For example, it is often necessary for customers to work closely with one or several providers to understand and utilize the potential of the new process technology in achieving innovative outcomes (Athaide and Klink 2009; Lee et al. 2010; Reichstein and Salter 2006). Similarly, interaction between providers and customers in process innovation allows firms to improve their value propositions by processing customer operational knowledge in conjunction with the full support of provider resource integration, knowledge, and skills – thus creating a novel solution that is very difficult for competitors to replicate (Vargo and Lusch 2008; Iebra Aizpurúa et al. 2011).

Grönroos (2012, p.1523) describes co-creation as "a joint collaborative activity by parties involved in direct interactions, aiming to contribute to the value that emerges for one or both parties." This is an important perspective to consider for understanding process innovation outcomes in ecosystems. Yet, prior literature has not provided a cohesive approach to understanding knowledge processing dynamics in process innovation and ecosystem perspectives are especially rare (Parida et al. 2018). Indeed, studies are spread across multiple disciplines within the entrepreneurship and innovation, marketing and operations managements disciplines. To provide a stronger conceptual basis for this study Table 1 presents an overview of studies of process innovation and their contributions towards understanding knowledge processing in value co-creation.

In essence, the review of literature shows that extending collaboration into value co-creation requires intensive knowledge-processing activities among ecosystem actors. For example, during the requirement definition phase of process innovation, the project is tasked with jointly mapping customer needs that may be largely unknown or imprecisely articulated and, from that weak base, forging a joint understanding of the customer's broader operational needs (Rönnberg Sjödin et al. 2016; Bruch and Bellgran 2012). This may include knowledge search to decrease uncertainty and equivocality towards understanding the internal operating processes, the established workforce and interdependencies among ecosystem actors so that requirements can be understood now, and in the future (Ahlskog et al. 2017; Eriksson et al., 2016; Kurkkio et al. 2011; Milewski et al. 2015). Grönroos & Voima (2013, p.141) explain the underlying co-creation logic for providers as "understanding the customers' practices and how customers combine resources, processes, and outcomes in interaction, the service provider shifts from a mere facilitator to a co-creator for value."

Indeed, co-creating value in process innovation is an integrative process requiring considerable interaction and sharing of knowledge among firms in the ecosystem, with input from a variety of actors from different backgrounds (Abd Rahman et al. 2009; Rönnberg Sjödin and Eriksson 2010; Robertson et al. 2012). For example,

Table 1 Overview of studies of process innovation and their contributions towards understanding knowledge processing in value co-creation

Author(s), year and journal	Type of study and sample	Key insights towards understanding knowledge processing in value co-creation for process innovation
Stock and Tatikonda (2008) *Journal of Operations Manamgenet*	Survey of 91 project managers of process innovation projects	External technology integration for process innovation will be most successful when the level of interaction between the source of the technology and recipient of the technology is appropriately matched to the level of technological uncertainty
Abd Rahman et al. (2009) *IEEE Transaction on Engineering Management*	Survey of 147 manufacturing companies	The higher the level of technological specificity and uncertainty, the more firms are likely to engage in a stronger relationship with technology providers. Developing strong relationships could lead to an improved performance in acquiring and implementing process innovations
Lager and Frishammar (2010) *Journal of Manufacturing Technology Management*	Conceptual paper	Presents a conceptual model of the full life-cycle of process technology to create a platform for determining collaboration intensity and success factors during different phases of value co-creation.
Rönnberg Sjödin and Eriksson (2010) *International Journal of Innovation Management*	Case studies of two process industry firms	Illustrates the benefits of an interconnected cooperative procurement approach in different stages of the equipment's lifecycle, in order to enhance value co-creation and knowledge processing both in provider--supplier dyads and among the providers and sub-suppliers in the ecosystem.
Frishammar et al. (2011) *IEEE Transaction on Engineering Management*	Case studies of four process industry firms	Shows that uncertainty and equivocality is more effectively reduced in successful early stage projects than in unsuccessful ones. The negative consequences of equivocality appear more critical to early stage performance than the consequences following uncertainty.
Rönnberg Sjödin, Eriksson and Frishammar (2011) *International Journal of Technology Management*	Case studies of two process industry firms	Strong collaboration is neither positive nor negative in general. Opportunities, problems, and collaboration intensity are strongly contingent on the specific stage in the lifecycle of process equipment. In addition, significant overlaps and interconnections exist across different stages and among ecosystem actors which need to be considered in value co-creation
Robertson et al. (2012) *Research Policy*	Conceptual paper	Proposes that process innovation requires specific innovative capacities that extend beyond knowledge management. Accessive capacity is needed to collect, sort and analyze knowledge from both internal and external sources. Adaptive Capacity is needed to ensure that new pieces of

Table 1 (continued)

Author(s), year and journal	Type of study and sample	Key insights towards understanding knowledge processing in value co-creation for process innovation
		equipment are suitable for the organization's own purposes even though they may have been originally developed for other uses. Integrative Capacity makes it possible for a new or modified piece of equipment to be fitted into an existing production process.
Bruch and Bellgran (2012) *Journal of Manufacturing Technology Management*	Case study of one process innovation project	Manufacturing companies have to transfer various types of design information with respect to the content and kind of information. More attention has to be placed on what information is transferred to ensure that equipment suppliers receive all the information needed to design and subsequently build the production equipment.
Milewski et al. (2015) *International Journal of Operations & Production Management*	Multiple case study of five large manufacturing companies	Asymmetric adaptation is needed to seek different levels of process standardization depending on the type of process they develop, which in turn affects whether there is a greater extent of technological or organizational change.
Rönnberg Sjödin et al. (2016) *Long Range Planning*	Survey of 52 process innovation projects in process industries	Equivocality reduces project performance, and joint explorative search allows for novel combinations of diverse knowledge and thereby alleviates the negative effect of equivocality on performance. Joint exploitative search allows for rapid learning based on the partners 'existing knowledge, but it also limits a team's ability to interpret and combine diverse knowledge which limits its effect on project performance.
Rönnberg Sjödin et al. (2016) *Journal of Engineering Technology Management*	Survey of 52 process innovation projects in process industries	Uncertainty and equivocality have negative effects on project budget performance. Project teams ca manage knowledge processing to reduce uncertainty through early end-user involvement, whereas equivocality can be reduced by joint problem-solving activities among customers and providers in process innovation.
Terjesen and Patel (2017) *Journal of Management*	Survey of 505 manufacturing firms	Search breadth is negatively related to process innovation outcomes and that search depth is positively related to process innovation outcomes. High industry process heterogeneity mitigates the negative impact of search breadth on process innovation such that firms employing broad search strategies in highly process heterogeneous industries are more likely to introduce process innovations. In industries with

Table 1 (continued)

Author(s), year and journal	Type of study and sample	Key insights towards understanding knowledge processing in value co-creation for process innovation
		greater productivity growth, the positive relationship between search depth and process innovation is stronger.
Von Krogh et al. (2018) *MIT Sloan Management Review*	Survey to 1000 manufacturing firms and a case study	Operations managers can build greater advantage for their company by following a policy of open process innovation involving multiple ecosystem actors rather than secrecy. Evolving from a closed to an open culture is not easy, and it generally requires taking several steps including opening up internally, focusing on pace and improving knowledge absorption from providers.
Ahlskog et al. (2017) *Journal of Manufacturing Technology Management*	Case study of a process innovation project	Three different knowledge integration processes exist when developing unique manufacturing technology: processes for capturing, for joint learning, and for absorb learning. The findings suggest that the three knowledge integration processes are highly interrelated with each knowledge integration process affecting the other two.

during implementation, the focus homes in on managing the complex task of coordinating multiple ecosystem actors responsible for installing the solutions, ensuring an efficient startup, and guaranteeing that everything works in the operational environment (Lager 2012; Rönnberg Sjödin 2013; Milewski et al. 2015). A key part of the implementation process is to understand the end users' operational capabilities and provide them with appropriate information or education to enhance their willingness and ability to co-create value in the future (Rönnberg Sjödin 2013). Successful value co-creation extend during the operational lifecycle to include upgrades and optimization of operational processes in response to the customers' evolving requirements (Rönnberg Sjödin et al. 2017). However, such extensions can also create complexity as multiple ecosystem actors may be interacting over an extended period which necessitates good relationships.

The review of literature provides an illuminating theoretical lens to the present study on process innovation in ecosystems, since we focus on investigating the challenges and response strategies for value co-creation in joint process innovation projects. As demonstrated, co-creating value in process innovation requires substantial knowledge sharing and collaboration among ecosystem actors if the requirements for success are to be met. Nevertheless, a limited number of studies have explored the challenges and strategies for knowledge processing that are relevant in seeking to extend the scope for value co-creation in joint process innovation. In particular, few studies consider these dynamics in the context of process innovation ecosystems. This paper argues that augmenting knowledge in this domain is important if our understanding of successful ways of achieving process innovation and ensuring value co-creation in ecosystem relationships is to be deepened.

Methods

Research approach and case selection

To gain a deeper understanding of the management of joint process innovation in ecosystems, this study adopts an exploratory multiple case-study strategy. Seeking an understanding of this phenomenon is a multifaceted and context-bound pursuit, and qualitative case studies can offer detailed insights and uncover substantial complexity reflecting both intra- and inter-organizational as well as individual processes (Eisenhardt and Graebner 2007; Edmondson and McManus 2007; Yin 2003). This approach is particularly appropriate given the limited knowledge on value co-creation processes that deal with process innovation in the manufacturing and process industry ecosystems.

In total, the case studies encapsulate the perspectives of seven providers and two customers of mechanical equipment active within ecosystem in the manufacturing and process industries (see Table 2). This study's approach thus captures a more holistic picture of the phenomena by involving informants from both sides to provide contextual richness to the analysis. The motivation for including both provider and customer

Table 2 Background information on case companies and informants

Firm	Main Business	Employees and turnover	Interviewees
Customers			
Alpha	Mining of iron ore and production of pellets	4500; 1900 M$	12 - Department Manager, Project Manager (5), R&D Manager (2), Controller, Purchasing Manager, Plant Manager, Minerals Technology Expert
Beta	Production of metal powders	1800; 830 M$ §	11 - Department Manager Tech Support, Engineer Tech Support, Marketing Manager, Vice President Global Development, Process Development Specialist, Senior Vice President, Manager Global IT Development, Production Manager, Global Supply Coordinator, Project Manager
Providers			
Delta	Mineral processing equipment	200; 150 M$	*4* - Product Manager, Project Manager (2), Sourcing Manager
Kappa	Mineral processing equipment	4900; 2100 M$	*3* - Product Line Manager, Manager Deliveries, Sales Director
Griffin	Industrial sieves	200; 21 M€	3 - Marketing Director, Manager Electronics, Sales Manager
Nippon	Industrial blenders	170; 25 M€	2 - Application Manager, Sales Engineer
Tiger	Automated cranes	8; 6 M€	3 - Vice President, Project Manager (2)
Alpine	Press tools	50; 6 M€	2 - Managing Director, Sales Director
Delphi	Presses	450; 60 M€	3 - Sales Manager, Production Manager, Department Manager

perspectives is twofold. First, the underlying premises of joint process innovation call for a deeper understanding of value co-creation in interactions between provider and customer. As most prior studies have focused principally on the provider's perspective on process innovation (Rönnberg Sjödin et al. 2011; Kurkkio et al. 2011; Lager, Schuman and Brent 2005), there is a need to integrate the provider's perspective in order to fully understand knowledge-processing challenges and strategies. Second, by taking a two-sided perspective, this study expands on the limited knowledge regarding how value co-creation processes unfold in this challenging context. Indeed, by gathering data from both sides, we are better able to understand relevant challenges and strategies concerning the management of knowledge in value co-creation.

Data collection

Data for the study were gathered primarily from 43 individual, in-depth, face-to-face interviews at these nine firms. The interviews ranged from 30 min to 2.5 h in duration, with an average of approximately one hour. To diminish bias in the data collection, knowledgeable informants from both the strategic and operational levels were selected, who viewed the collaborative relationships within the ecosystem from diverse perspectives (Eisenhardt and Graebner 2007). The informants were selected carefully in dialogue with key informants at the participating firms, based on their involvement in and knowledge of collaborative projects involving customers and providers and other ecosystem actors.

The interviews were semi-structured and guided by a list of questions concerning value co-creation activities, challenges and strategies in joint process innovation. The interview questions were generated from the literature review of the subject (i.e. the process innovation, value co-creation, and ecosystem collaboration) and personal experience gained from prior studies within the process and manufacturing industries, as well as from informal discussions with knowledgeable individuals from the industries involved in the early phase of the study. Data were gathered on the organizational level, but examples from recent projects were encouraged in order to provide illuminating details. Departures from the specific questions were permitted in order to explore particularly interesting themes that emerged during the study. Accordingly, the format of the interviews was adapted slightly to capture these emergent themes (Eisenhardt 1989).

Data analysis

The data collected was analyzed by using the thematic analysis method (Braun and Clarke 2006), which employs an iterative series of steps to identify themes so that an empirically grounded framework can be developed from the qualitative data.

The first step in the data analysis focused on in-depth analysis of the raw data (e.g., interview transcripts). We familiarized ourselves with the data by reading each interview several times, each time marking phrases and passages that were interesting and noting down initial ideas. The second step entailed coding of common and relevant words, phrases, terms, and labels mentioned by informants that were connected to the overall research purpose (i.e. first-order categories of codes). These codes expressed the informants' views in their own words. For example, the following statement by a plant manager at Betacorp underlining the independence of process technologies was coded as systemic dependencies related to other equipment.

> The complexity of the process can cause problems in the development of new process technologies. We bought new and improved equipment for our powder plant but it affected the entire process as it was insufficiently reliable.

The third step involved further analysis of the initial codes and comparing them to prior literature to discover links and patterns in the codes so that various themes could be identified. In a fourth step, the themes were further refined (i.e., second-order themes were developed), and a thematic map was generated to provide an overview of the data based on the interplay between interview data, prior literature and secondary sources such as internal documents, presentations, industry reports, and so on. For example, the above-mentioned code was clustered with codes relating to the difficulties in understanding complex technology integration in order to formulate the theme complexity. In the fifth step, the specific focus of each theme was refined and related to the overall story of the analysis as well as to the literature. Accordingly, this analysis resulted in a thematic map consisting of several themes relating to, for example, technological challenge and knowledge-processing requirements for value co-creation in process innovation (i.e., aggregate dimensions). For further details on the themes in the data structure, see Fig. 1.

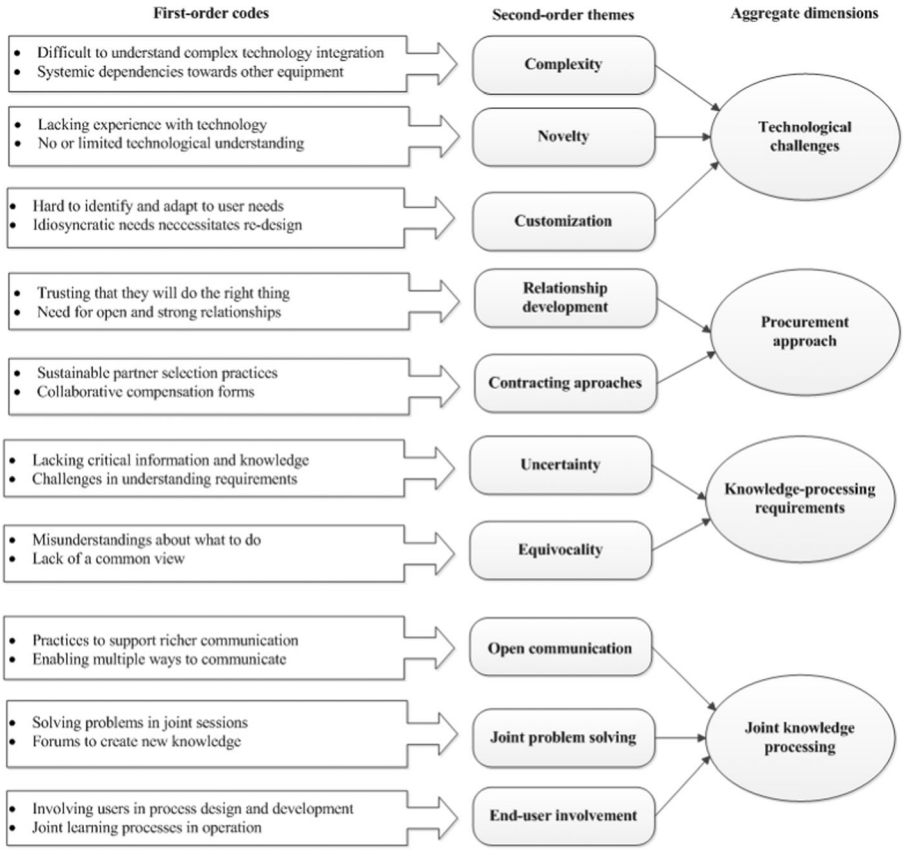

Fig. 1 Data structure

During the analysis process, the preliminary results were discussed extensively with knowledgeable colleagues and industry professionals to arrive at valid results. To increase reliability and transparency and to reduce the potential for replication, a case study protocol was constructed along with a case-study database. The database included case-study notes, documents, and analysis. In total, these steps enabled us to develop an empirically driven theoretical framework that linked various phenomena emerging from the data analysis.

Empirical findings

Several insights emerged from studying the challenges and response strategies for value co-creation in joint process innovation projects. A data structure that represents a summary of the findings is illustrated in Fig. 1. The data structure emerged from the analysis of the informants' statements and reported experiences in the context of process innovation within ecosystems. The identified patterns are captured and validated from both sides of the ecosystem, which means that informants from both providers and customers recognized them as being influential in explaining value co-creation outcomes. The specifics of the findings are further described in the following sections.

Technological challenges

Informants emphasized that process innovation projects have many challenging characteristics since process technologies are often complex and highly customized, and implementing novel solutions is typically a risky endeavor that needs to be managed carefully.

First, the findings illustrate that *complexity* is an inherent challenge in joint process-innovation projects due to the characteristics of the development work. A key challenge is that process technologies are highly systemic – i.e. informants described how the performance of each subsystem (e.g. a piece of equipment) depends on the performance of its components, whilst influencing and being dependent on the performance of higher-order systems at the same time. A department manager at Alphacorp highlighted this issue:

> A process plant is very complex… Control systems must work with the equipment, and the equipment must conform to later process steps, and the equipment itself is often very large with high demands for reliability and low maintenance costs.

In particular, the amount of equipment and the number of interactions among various types of equipment during process innovation increases both the complexity and the information-gathering requirements to advance the development efforts. For example, the effects of changes in one part of the process are difficult to predict due to interdependencies among different process parts. It also introduces interdependence among multiple providers within the ecosystem. In particular, changes in one piece of equipment may affect the material characteristics in later steps. A senior executive at Betacorp spoke about this complexity:

> Frequently, it is three or four different factors that affect the process and if you change one then it affects the others, and you may not get the result you expect, and this is a key challenge.

A crucial challenge underlined by informants is the way in which the inherent complexity increases reliance on judgment and experience rather than on simple formulae or engineering calculations. This can make it hard for ecosystem actors to determine the appropriate way to design new process solutions without experience of the process behavior. In particular, the development of process technologies is often characterized by cause-effect relationships that are not well understood, which increases the difficulty in enacting shared interpretations among a multitude of ecosystem actors involved.

Novelty is another challenging aspect during joint process innovation. While new technologies often offer the prospect of significant performance improvements (e.g., increased energy efficiency), informants suggested that most customers were still hesitant to adopt them because of the challenges involved. In particular, novel technologies require designing solutions that may not have been previously encountered. In this scenario, no one really knows how the technology will behave in the new process, and so careful experiments and simulations are necessary to manage the risk. Specifically, informants felt that the frequency of unexpected and novel problems is likely to increase during development when novel technologies are deployed. This makes it challenging to predict problems or to design activities in advance, creating an on-going need to collect, share, and discuss knowledge among ecosystem actors for the purpose of determining what is occurring and of dealing with disruptions. A production manager at Betacorp underscored the issue in these words:

> If it concerns equipment that we already have, it is easy. But, if we are developing something new, a lot of discussion and information exchange back and forth is required.

Customization addresses the degree to which the technology of interest must conform to an existing interface or process, or must be adapted to fit the needs of a particular system in use. Examples include situations where the technology of interest is intended to become part of a particular production process or to be adapted to fit existing hardware or software systems (e.g. control systems). Due to idiosyncratic and highly complex production requirements, process technologies are often highly customized. A department manager at Alphacorp explained this issue as follows:

> This is the main point with co-creation to develop something that satisfies our needs. If we have a need and we can't buy something that satisfies our needs in the market, we will have to work closely with the provider to customize the equipment to meet our needs and make sure that they understand the necessary adaptations to our application.

Accordingly, higher levels of customization increase the need for knowledge gathering by the providers since the technology is adapted to fit new applications. Accordingly, customization requires significant interaction with users, allowing them to share

knowledge to influence the technology's characteristics. In particular, customization implies a need for customers to enact a shared understanding of process requirements together with the providers within the ecosystem so as to make the necessary adaptations to the equipment.

Knowledge-processing requirements

The inherent characteristics of joint process innovation projects create a need for knowledge processing to enable co-creation of new process solutions among ecosystem actors. As indicated by the analysis, two key knowledge-processing requirements are important in the context of joint process innovation, uncertainty and equivocality.

Uncertainty refers to the difference between the information available and the information needed to complete a task. The informants emphasized that the requirements for getting the right data and information – and identifying how and where to get it – was a key challenge for the development organization. A department manager at Alphacorp discussed the inherent uncertainty of process innovation:

> Even if we have done a good pre-study, we don't have all the answers about how things should be constructed and implemented. This means that during the journey [i.e., project] new information will come up, which means that we have to do things in a different way compared to our earlier thoughts.

Equivocality refers to the extent to which multiple and conflicting interpretations of the information exist among multiple participants in a project. Indeed, informants agreed that a key challenge was related to the difficulties in interpreting information and knowledge among many different ecosystem actors involved in value co-creation. For example, different functional backgrounds, experiences and operational cultures would lead project participants to experience a degree of confusion and a lack of understanding concerning the goals pursued and the problems to be solved when engaging in joint process innovation. The more actors are involved, the more this may become an issue. A department manager at Betacorp described such problems as follows:

> Sometimes communication fails and you have different interpretations in terms of what is to be developed, and sometimes this is not discovered until late in the development. It can be very similar interpretations that make you think that you understand each other but still differ on important functions.

The early stages of a project would typically have much higher levels of uncertainty and equivocality due to limited understanding of the task among ecosystem actors. However, many informants identified examples of when the project organization had all the information required to proceed with development (i.e., low uncertainty) but still struggled to move forward because of different interpretations concerning what needed to be accomplished (high equivocality). Informants also described that unresolved uncertainty and equivocality could lead to a waste of resources as project participants encounter lack of clarity, failing to develop a shared interpretation of what to do, when to do it, and how to do it. Indeed, a production manager at Betacorp intimated that communicating their needs to ecosystem providers can be a key problem:

> In most cases, it's a matter of sharing information – we know what we want and think it is obvious, but perhaps that is not always the case.

Joint knowledge processing

Value co-creation activities imply drawing on and integrating knowledge from different sources in the customer and provider organizations to create the most valuable solutions for customers. Integrating knowledge from different individuals requires direct personal interaction to reduce the risk of equivocality and misunderstanding. A common them among informants was that the more challenging the technological solutions, the more important the personal and communication-intensive forms of integration in the value co-creation process become. In particular, richer forms of open communication and joint problem solving, as opposed to rigid routines and hierarchical systems, are particularly important when working in temporary project-based settings in the context of joint process innovation.

The issue of *open communication* is particularly important since miscommunication – which causes conflict and misunderstanding between ecosystem partners – is recognized as the cause of many collaboration failures. Indeed, many informants pointed to the need for open discussions, debates, and extensive communications among ecosystem actors on a regular basis during development since project participants are likely to face many technological and functional challenges during the course of the project. For example, a mechanical engineer at Tiger indicated that intensive communication is typically required during the early stages of co-creation:

> Because I need their input to do the design, there is communication back and forth until we know what should be done. This is usually most intensive at the beginning of the project.

Informants mentioned the co-location of engineers, group meetings, and the use of advanced IT tools as appropriate methods that serve to increase the clarity and richness of communication and promote shared understanding within the ecosystem. For example, IT tools such as three-dimensional (3D) models and simulations can be used to facilitate rich discussions and knowledge processing among partners. However, knowing what to share can sometimes be a challenge as a senior executive from Betacorp underscored:

> It can sometimes be difficult to know what information you can share with them and what they need to know to develop the equipment, and I think this is a key problem in collaboration.

Joint problem solving was found to be a key input in the success of co-creation, suggesting an on-going interactive process of mutual effort undertaken by the collaborating partners to diagnose, formulate and address obstacles that block project effectiveness. In the context of process innovation projects, joint problem solving can be seen as a rich form of interaction, facilitating coordination among ecosystem actors and resolving potential problems during development. For example, informants noted the benefits of organizing joint sessions with representatives from various functions/competencies within provider and customer organizations where the parties would

discuss on-going developments, share opinions and interpretations, and make collective decisions regarding solution alternatives. The key benefit of this approach is that it provides a forum for face-to-face interaction in the project organization, and it facilitates deeper interactions and shared interpretations that help the development team move the project forward. For example, a project manager at Tiger argued that joint problem solving is an important ingredient in the success of joint process innovation efforts:

> The collaboration has been excellent; it has been mutual efforts from both sides. Discussing ideas, getting feedback, and if any problems occur, being able to discuss them together and jointly finding a good solution.

As informants indicated, joint problem-solving sessions are especially important for more innovative projects that function as arenas for experimentation with different information and ideas in problem-solving endeavors. For example, joint problem-solving sessions in which providers can demonstrate new solutions in a hands-on setting are a highly effective means of solving problems and conveying information that is technically complex and difficult to articulate. Informants described how ecosystem partners could provide alternative interpretations of technical problems and solutions, which then enabled them to compare and triangulate different perspectives and potential solutions. For example, a department manager at Alphacorp described the benefits of a joint problem-solving approach as follows:

> I think this approach of working together and trying to look at a problem from different perspectives utilizing our diverse knowledge is vital for us to succeed with innovating our production processes.

End-user involvement is particularly important for joint process innovation. Commonly informants stressed that end users (i.e. senior engineers and lead operators in maintenance and operations) have a unique understanding of the problems encountered in production processes and can supply critical information about the operational requirements of the equipment, given their deep practical experience. Therefore, their insights are important in identifying potential problem areas and information gaps so that effective solutions can be developed. For example, informants stressed that knowledge of the complex interdependence among material inputs, the specific process technologies, and the overall production processes is typically tacit and gained through 'learning by doing'. The importance of the level and timing of end-user involvement is illustrated by informants from two similar projects between Alphacorp and Silver:

> In Project A, end users were only involved during installation of the plant. As a result, late changes to the design were proposed and implemented due to limited information about end-user needs during the design work, which increased costs and created delays during implementation. In contrast, during Project B, the end users were intensively involved throughout the project. In this case, Silver's project manager was amazed at the lack of change orders and speedy start-up of the equipment.

However, informants also cautioned that end-user involvement may also increase equivocality among ecosystem actors because it would typically add another layer of differing

views and interpretations from large numbers of functionally and organizationally diverse project participants. Accordingly, whenever new participants enter the project, the experienced project manager would employ richer forms of communication such as joint meetings to reach a common understanding and to crystallize expectations of the work ahead.

Procurement approach

To enable value co-creation in joint process innovation, the procurement approach of the partnerships is a key enabler of good outcomes. Indeed, the analysis indicated that relationship and contracting approaches were key in facilitating a collaborative environment for value co-creation within the ecosystem. The issue at hand is finding partners with the appropriate technical knowledge and ability, commitment, and long-term collaborative orientation. A careful choice of the right partners can, therefore, facilitate value co-creation.

Using appropriate *contracting approaches* was underscored as a crucial way to enable value co-creation. A valuable lesson from informants was that it was often harmful to co-creation to rely on competitive tendering. This competition to offer the lowest price increased the risk of conflict and, by putting a squeeze on profit margins, limited the equipment provider's scope to allocate the personnel resources needed to achieve value co-creation with the customer. For example, providers within the ecosystem may compete to get only their work done thus sub-optimizing the ecosystem innovation. Their Rather, most of the informants argued that focusing on the competencies and the duration of prior relationships between the parties was a relevant criterion to consider – the logic being that collaboration over an extended period of time can lead to the development of shared routines and practices, enabling the ecosystem actors involved to collaborate more effectively. A department manager at Alphacorp illustrated his company's preferences when selecting partners:

> We primarily select providers that we trust and feel have the appropriate technical competencies to work with in these projects, and this is often based on our earlier experiences and contacts.

Another favorable contracting approach suggested by informants was the use of incentive-based payment such as open-book accounting coupled with gain/pain share arrangements in relation to a negotiated target price. Informants agreed that such agreements give the provider extrinsic motivation to perform well and ensure that all parties within the ecosystem are working towards a win-win situation. A project manager at Silver described the benefit of this approach:

> The use of open books really improved the collaboration in the project…We didn't have to argue over change orders or increased cost but could focus our efforts on solving problems.

As indicated by informants, gain/pain share arrangements and bonus opportunities are especially helpful in larger and more complex process-innovation projects where many interdependent equipment providers and sub-providers within the ecosystem are integrated. In this situation, the partners are motivated to work jointly towards a common

objective instead of sub-optimizing their own individual parts. Such collaborative approaches facilitate knowledge processing and are of special importance in enabling the sharing of important knowledge across partners.

Relationship development (e.g. trust, information sharing) was identified by informants as a key enabler of value co-creation in the ecosystem because it reduces friction in the interactions between the parties, making them more comfortable and motivated to increase the scope of their relationships. Trust allows partners to have confidence in the information and advice provided by other ecosystem actors and to believe that the recommendations put forward are in their own best interests. Consequently, many informants suggested that trust is much more important that the actual provisions stipulated in the contract for co-creation to work. Indeed, informants indicated that relying too much on contracts could increase opportunism and that developing trust and shared norms was often a better enabler of good outcomes. A department manager at Alphacorp highlighted these issues:

> In some projects, you feel quite clearly that work is only conducted within the contract and this is often because of a lack of trust among the parties. On the other hand, some projects work so well that you shouldn't even need a contract.

As the informants indicated, trusting ecosystem relationships can generate a number of efficiencies in knowledge processing by conserving cognitive resources, lowering transaction costs, and simplifying decision making. An added benefit is more open sharing of information to benefit the project. Accordingly, trust often increases the efficacy of communication among partners and also facilitates value co-creation during the different stages of the project. A project manager at Alphacorp emphasized the critical role of trust in enabling value co-creation:

> There is one key success factor – trust among the project participants. If you don't have trust the collaboration will never work. You need to motivate people and make sure that they trust each other to facilitate open discussion.

Towards an understanding of value co-creation in joint process innovation

Based on the empirical findings and prior literature, we propose an emergent framework for managing co-creation in joint process-innovation projects, highlighting the interdependence between knowledge-processing requirements and joint knowledge processing among the ecosystem actors involved at different stages. The framework starts with an idea for a process innovation initiative which needs to be managed. The framework can be used – before work starts – to plan collaboration by assessing the technological challenges and selecting appropriate procurement approaches and – during co-creation – by monitoring knowledge-processing requirements and adjusting joint knowledge processing within the ecosystem to ensure process innovation performance. The main relationships and propositions of the framework are outlined in Fig. 2.

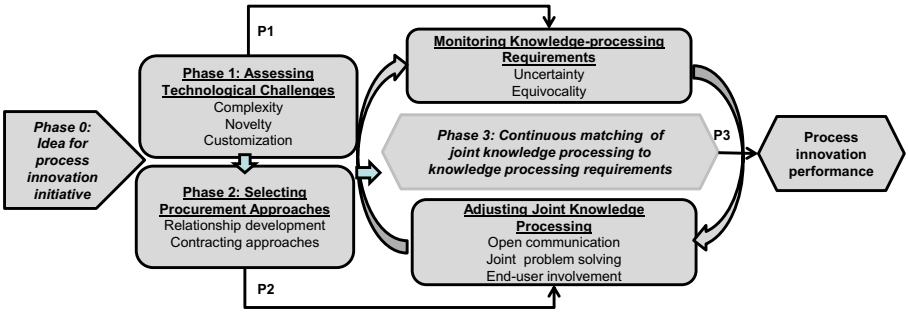

Fig. 2 A framework for managing value co-creation in joint process innovation

First, the findings suggest that complexity, novelty, and customization are interrelated project characteristics that increase the need for knowledge processing among customers and providers of process equipment but, at the same time, increase the potential for knowledge gaps in terms of uncertainty and equivocality. Accordingly, we propose that, in the initial phase, assessing knowledge processing challenges is a key first task for project managers charged with conceiving new process innovation projects. For example, a senior manager at Betacorp recounted an example where the firm had underestimated the complexity of developing new equipment jointly with Nippon and sub-suppliers and was faced with high levels of uncertainty and equivocality in the project, which lead to significant problems in understanding each other during the design phase and ultimately ended in poor project performance. Thus, it is proposed that:

> *P1: Higher technological challenges in the form of complexity, novelty and customization will increase the knowledge-processing requirements (uncertainty and equivocality) in joint process innovation projects.*

Second, the findings suggest that, in a second phase, managers should evaluate the technological challenges when selecting procurement approaches – such as relationship development and contracting – since these can facilitate joint knowledge processing (e.g., joint problem solving) within the ecosystem. Indeed, the informants suggested that, in procuring providers for process innovation projects, careful attention needs to be given to assessing the potential of the customer-provider and ecosystem co-creation partnerships to address these technological challenges. For instance, decisions made during the procurement of providers – such as partner selection and compensation forms – will affect the potential to achieve value co-creation through extensive joint knowledge processing over the duration of the project. An example of the opposite scenario was recounted by a project manager at Silver where high cost pressures and low trust with the customer led to adverse relationships in which a willingness to work together and share information was absent within the ecosystems leading to poor performance. Thus, it is proposed that:

> *P2: More collaborative procurement approaches in the form of relationship development and contracting will increase the knowledge-processing potential in joint process innovation projects.*

Third, the results of this study highlight the importance of monitoring knowledge-processing requirements in the form of uncertainty and equivocality and adjusting joint knowledge processing during value co-creation activities among ecosystem actors. Specifically, it is suggested that the level of joint knowledge-processing activities should match the level of knowledge-processing requirements. Thus, project managers should plan the project to match knowledge processing over the various stages in order to achieve effective performance. As the informants asserted, it is important to have a clear view of potential problems and the activities required through the different stages of the project. For example, it may be advisable to involve new ecosystem actors or roles in the project early on, since deficient knowledge processing in the initial stages can be very difficult to correct at a later stage, and it can often lead to mistakes in the process design. However, it is important to note that new knowledge-processing requirements may emerge over time as in the case of, for instance, installation and start-up where design mistakes and learning gaps are often discovered. Essentially, the level of knowledge processing ought to be matched to the discrete requirements of each phase. Thus, a key task of project managers is to continuously match the level of joint knowledge processing with the level of knowledge-processing requirements. For example, a project manager at Alphacorp recounted how he continuously monitored the project to assess the need for more intensive value co-creation activities.

Assessing the performance of process innovation projects, this paper's findings suggest that failure to address prevailing uncertainty and equivocality increases the risk of delay, and work could well proceed on the basis of faulty assumptions leading to mistakes in design, the need for re-working and last-minute changes. Indeed, a common theme in the data was that projects unable to manage high levels of uncertainty and equivocality among partners were characterized by cost overruns, time delays, quality problems and ultimately unsatisfactory results, while projects able to hold these challenges in check were more successful. Thus, it is proposed that:

> *P3: Matching joint knowledge processing such as joint problem solving, open communication and end-user involvement to knowledge-processing requirements in the form of uncertainty and equivocality has a positive effect on project performance in joint process innovation projects.*

Table 3 provides a practical tool summarizing the implications of the proposed framework and earmarks the key questions for joint process innovation project managers. The table can be used to glean insights into planning how best to engage in value co-creation processes before work starts: with whom to collaborate, by what methods, and during which stages.

Discussion

Value co-creation is central to the knowledge intensive task of joint process innovation in ecosystems. Previous literature has indicated the importance of understanding the interactions and challenges in value co-creation relationships relating to process innovation outcomes (Eriksson et al., 2016; Rönnberg Sjödin et al. 2016; Lager and

Table 3 A practical tool for managing value co-creation in joint process innovation

Component	Key questions(s)	Implication
Technological challenges	How challenging will this project be to undertake?	Increases knowledge processing requirements
Complexity	How complex is the technology and the interdependencies with other operational systems?	
Novelty	Do we or others in the ecosystem have experience with this technology?	
Customization	To which degree would technologies need to be adapted to fit user requirements?	
Procurement approach	How shall we approach the ecosystem co-creation partnerships to address the technological challenges?	Facilitates increased joint knowledge processing
Contracting approach	How can we select innovation partners to ensure appropriate levels of value co-creation?	
Relationship development	How can we ensure partnerships capable of handling technological challenges?	
Knowledge processing requirements	What level of knowledge processing gaps are we facing?	Increases the risk of project failure
Uncertainty	Are we lacking any key information or knowledge to proceed with this project?	
Equivocality	Do we understand each other and the knowledge available within the project?	
Joint knowledge processing	How should we jointly address the knowledge gaps in this project?	Reduces knowledge gaps to increase the odds of successful project performance
Open communication	How can we secure the sharing of appropriate information in this project?	
Joint problem solving	How can we jointly combine our knowledge to solve innovation problems?	
End-user involvement	How can we ensure that end-user perspectives are captured throughout this project?	

Frishammar 2010). Nevertheless, this literature provides scant insights into how multiple actors manage the significant knowledge-processing challenges inherent in such projects. In an effort to fill this gap, this study contends that much can be learned by studying the dynamics of knowledge processing in value co-creation for process innovation. Thus, this study provides insights into how firms can manage knowledge processing for value co-creation in ecosystems.

The paper provides an organized approach to understanding how value co-creation is challenged by three types of technological challenge (complexity, novelty, customization), which demand significant knowledge-processing requirements (uncertainty, equivocality) that need to be managed. This empirical study has described how customers and ecosystem actors engage in various knowledge-processing activities (joint problem solving, communication, end-user involvement) to handle the ongoing need for knowledge processing. To this end, an appropriate selection of a

procurement approach (contracting, relationship development) provides the foundations for value co-creation and joint knowledge processing within the ecosystem. This study, therefore, offers important insights into the knowledge-processing dynamics of ecosystem relationships in the context of value co-creation in process innovation (e.g., Robertson et al. 2012). The mechanisms identified provide a foundation for developing more comprehensive and detailed research on how process innovation problems are managed among customers and ecosystem actors as they engage in co-creating value.

The findings have important implications for research within the literature on process innovation, co-creation of value, and project management, as well as for management practice. The importance of these findings is underscored by the increasingly distributed nature of innovation (Gama et al. 2017), where not only product innovation but also process innovation becomes more open and distributed among ecosystem actors (Robertson et al. 2012; Von Krogh et al. 2018). The insights are particularly important for understanding the current era of digitalization where ecosystems are increasingly required to co-create novel process innovation arising from the advances in artificial intelligence and automation and application of digital technologies (Iansiti & Lakhani 2014; Porter & Heppelmann 2014; Sjödin et al. 2018) for sustainability benefits.

Theoretical implications

This current study has several important theoretical implications for the literature on process innovation, value co-creation and knowledge management in ecosystems.

First, this study contributes by conceptualizing process innovation as a knowledge-intensive process focused on inter-organizational problem-solving activities that involve the creation and recombination of technological knowledge among ecosystem actors (Terjesen and Patel 2017; Milewski et al. 2015; Eriksson et al. 2016). By introducing knowledge-processing requirements as explanatory variables in the context of joint knowledge processing activities, governance structures and contract arrangements that facilitate effective implementation and value creation this study develops significant contributions to the emerging literature on value co-creation in process innovation and ecosystems (Eriksson et al. 2016; Robertson et al. 2012). Focusing on the management of knowledge-processing challenges that shape the co-creation process the current framework emphasizes an interactive approach among ecosystem actors. Although joint knowledge processing is a key foundation of value co-creation, it has received scant attention in the extant research literature on process innovation (Grönroos and Voima 2013; Milewski et al. 2015; Kurkkio et al. 2011; Terjesen and Patel 2017). Specifically, the present study identifies critical knowledge related barriers to co-creating value in the form of uncertainty and equivocality, which may provide further insights into failure in process innovation (Rönnberg Sjödin et al. 2016). For example, the results suggest that the origin of many co-creation challenges between customers and ecosystem actors (e.g. providers, sub-suppliers) is to be found in participants' failure to integrate knowledge so that no common and shared interpretation of project tasks is established (i.e. equivocality). In this light, we view the concept of knowledge-processing requirements as particularly illuminating to value co-creation outcomes in ecosystems.

Second, managing process innovation represents an iterative co-creation process involving the reciprocal exchange of information and knowledge between customers

and providers within the ecosystem (Bruch and Bellgran 2012; Grönroos and Voima 2013; Rönnberg Sjödin et al. 2016). This study makes a contribution by developing a detailed framework which captures the interactive strategies adopted in knowledge processing and proposing key relationships between constructs as a basis for further studies and theoretical contributions. By providing an increased understanding of the interplay between knowledge-processing requirements and joint knowledge-processing activities (Eriksson et al. 2016), we add richness and detail to novel constructs, which will hopefully stimulate researchers in the general field of value co-creation and process innovation to build stronger theories in this important domain. Critical to understanding knowledge processing interplays is the role of technological challenges and procurement approaches in setting the foundations for ecosystem co-creation. For example, a highly challenging project where complexity and novelty is high is proposed to have a higher likelihood of high knowledge processing requirements in the form of uncertainty and equivocality. Similarly, trust and strong relationships among partners is held to be particularly important in facilitating richness in joint knowledge processing and in ultimately reducing equivocality. To this end, the framework should be of special relevance to researchers interested in the management of joint process innovation projects (e.g., Abd Rahman et al. 2009; Bruch and Bellgran 2012; Robertson et al. 2012; Stock and Tatikonda 2008) but also to those undertaking research more generally on ecosystem collaboration in innovation projects (e.g., Gama et al. 2017) and open innovation (e.g., West and Bogers 2014). The analysis and developed framework will enable scholars to develop more detailed frameworks in studying negative and positive outcomes of technological challenges and knowledge processing requirements, as well as to develop further theoretical contributions from the study of knowledge management dynamics in ecosystem relationships.

Third, this paper provides a more dynamic and evolutionary view of knowledge-processing requirements evolving over the different phases of innovation in the context of joint process innovation (Robertson et al. 2012). By taking such a perspective, this study contributes not only to the knowledge management literature (Grant 1996; Zack 2001) but also to the process innovation literature that is currently emerging (Terjesen and Patel 2017). While commonly held as static challenges inherent in the project composition, this study illustrate how uncertainty and equivocality can vary over the life of process innovation projects. For example, the results show that knowledge-processing needs may vary depending on project characteristics (e.g., complexity, novelty) and the specific stage (e.g., pre-study, start-up) of the project. By emphasizing how development progresses and by identifying the different elements of knowledge-processing requirements, this current research extends the existing framework by outlining how ecosystem actors manage uncertainty and equivocality over the co-creation relationships. The key proposition is that the degree and type of joint knowledge-processing activity should be matched to the knowledge-processing requirements at specific stages in order to achieve effective performance. This paper thus contributes by extending traditional information-processing theory to the context of process innovation and including both uncertainty and equivocality in the discussion (Tushman & Nadler 1978). Overall, this creates opportunities for developing a deeper understanding of how the presence of knowledge-processing requirements in certain phases accounts for success in joint process innovation from a value co-creation perspective.

Managerial implications

The current paper holds several practical implications. First, ecosystem actors from customer and provider sides are encouraged to discuss a project's aims, objectives, specific characteristics, and challenges through the proposed framework and to communicate them to the different functions responsible for implementing the range of possible processing options already undergoing development. By analyzing and quantifying knowledge-processing requirements and possible joint knowledge-processing activities, managers can better understand the challenges of the project and choose value co-creation methods that are adequate to the task. In particular, greater uncertainty means more knowledge-processing requirements in terms of knowledge collection, analysis, and sharing, while greater equivocality requires increased joint efforts in problem definition and explanation among the parties. For this purpose, evaluation of the characteristics of the projects is required, and the procurement approaches and joint knowledge processing activities need to be adapted accordingly.

Second, project managers can assess the potential challenges over the different life-cycle stages and ensure that appropriate knowledge-processing activities are conducted when needed. Because of stage interdependence, knowledge processing in the early stages is often required for the work to proceed through the later stages (Rönnberg Sjödin et al. 2011; Rönnberg Sjödin and Eriksson 2010). Ecosystem partners should, therefore, focus on achieving a match between knowledge-processing requirements and joint knowledge-processing activities over the different stages of the project in order to reduce knowledge gaps. However, in the traditional model of joint process innovation, no acknowledgment is made of the fact that the volume and richness of the co-creation activities need to vary according to the situation and the specific challenges of the particular stage in the innovation process. In particular, project participants may struggle with different technical and organizational problems consequent on different knowledge-processing needs at each stage. These can vary significantly over the course of a single project or over the life cycle of a technology as it proceeds from early development to implementation. In particular, new knowledge gaps in terms of uncertainty and equivocality may arise or be discovered during the course of a project as new ecosystem partners are involved. For example, the level of uncertainty and equivocality is typically highest in the early stages, and thus extensive knowledge processing is key in value co-creation to avoid future mistakes. However, it may be the case that too few resources are devoted to communication and joint problem solving in the early stages. In particular, a lack of fit between knowledge-processing requirements and joint knowledge-processing activities can lead to an inability to pre-plan, which increases the amount of knowledge that has to be processed during task execution. This is a form of sub-optimization since reducing knowledge gaps at later stages will be increasingly costly, with the likelihood of late changes, disruptions, and problems increasing significantly.

Third, while prior research has noted the high failure rates of process innovation projects with challenging characteristics (Fillipou & King 2012; Lager 2011), the findings highlight the fact that contextual characteristics such as technological novelty and complexity are not necessarily negative in themselves; rather, it is the consequences of these factors in the form of unresolved uncertainty and equivocality that is likely to cause problems among ecosystem actors. As a countermeasure, firms can engage in

joint knowledge-processing activities to reduce uncertainty and equivocality. In other words, the issue is not to avoid projects with challenging characteristics; rather, the appropriate response is to properly manage the project in line with its characteristics to avoid the negative aspects and, at the same time, to seize the opportunities that it creates. However, given the quite intensive resource commitments required to reduce knowledge gaps, a somewhat conservative approach may still be advisable.

Limitations and outlook

The present study relies on in-depth case studies of nine industrial ecosystem actors operating in manufacturing and process industries in Northern Europe. Thus, the findings should be understood to apply primarily to contexts characterized by similar conditions (e.g. stable institutions, trust, low clockspeed). For example, process innovation in other industries (e.g., semiconductors) would probably face other types of dynamics. Although the empirical basis for the conclusions is rather broad, we realize that future work on managing knowledge processing in value co-creation could differ from this study's findings on the basis of cultural differences and distance (Anderson and Hardwick 2017). Adding cultural differences to the architecture of the present study may be rewarding, since different types of value co-creation have been found to be more or less effective, depending on the context (Cossío Silva et al. 2013).

The proposed framework advances the discussion on value co-creation in ecosystems for process innovation, offers a framework for conceptualizing the links among interrelated concepts, and provides a starting point for further work in this important area. Thus, this framework should stimulate additional theory building and conceptual innovation in entrepreneurship and innovation management disciplines. Given the emerging nature of the framework, the proposed relationships should be considered tentative and subjected to further refinement through both qualitative and quantitative research methods. For example, researchers may follow knowledge development in an innovation ecosystem over time and which roles various actors take at different phases of development. In addtion, further quantitative project-level studies of process innovation and various aspects of value co-creation should be conducted – for example, investigating different strategies on knowledge processing and the impact of absorptive capacity in managing knowledge-processing requirements in process innovation. Thus, the contents and proposed relationships among constructs in the framework are still open for discussion and validation in future studies.

Finally, the results suggest that proficient knowledge and management of ecosystem co-creation in process innovation offers significant opportunities for new entrepreneurial ventures (Mary George et al. 2016). While most prior research has focused on venture success driven by product innovation, further studies could usefully investigate whether process innovation can also serve as a source of competitiveness for new ventures and how this can this can be facilitated through ecosystem co-creation.

Open Access This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

References

Abd Rahman, A., Brookes, N. J., & Bennett, D. J. (2009). The precursors and impacts of BSR on AMT acquisition and implementation. *IEEE Transactions on Engineering Management, 56*(2), 285–297.

Ahlskog, M., Bruch, J., & Jackson, M. (2017). Knowledge integration in manufacturing technology development. *Journal of Manufacturing Technology Management, 28*(8), 1035–1054.

Anderson, A. R., & Hardwick, J. (2017). Collaborating for innovation: The socialised management of knowledge. *International Entrepreneurship and Management Journal, 13*(4), 1181–1197.

Athaide, G. A., & Klink, R. R. (2009). Managing seller-buyer relationships during new product development. *Journal of Product Innovation Management, 26*(5), 566–577.

Barnett, B. D., & Clark, K. B. (1998). Problem solving in product development: A model for the advanced materials industries. *International Journal of Technology Management, 15*(8), 805–820.

Becheikh, N., Landry, R., & Amara, N. (2006). Lessons from innovation empirical studies in the manufacturing sector: A systematic review of the literature from 1993–2003. *Technovation, 26*(5), 644–664.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101.

Bruch, J., & Bellgran, M. (2012). Design information for efficient equipment supplier/buyer integration. *Journal of Manufacturing Technology Management, 23*(4), 484–502.

Cossío Silva, F. J., Revilla Camacho, M. A., & Vega Vázquez, M. (2013). Heterogeneity of customers of personal image services: A segmentation based on value co-creation. *International Entrepreneurship and Management Journal, 9*(4), 619–630.

Daft, R. L., & Lengel, R. H. (1986). Organizational information requirements, media richness and structural design. *Management Science, 32*(5), 554–571.

Edmondson, A. C., & McManus, S. E. (2007). Methodological fit in management field research. *Academy of Management Review, 32*(4), 1155–1179.

Edvardsson, B., Tronvoll, B., & Gruber, T. (2011). Expanding understanding of service exchange and value co-creation: A social construction approach. *Journal of the Academy of Marketing Science, 39*(2), 327–339.

Eisenhardt, K. M. (1989). Building theories from case study research. *Academy of Management Review, 14*(4), 532–550.

Eisenhardt, K. M., & Graebner, M. E. (2007). Theory building from cases: Opportunities and challenges. *Academy of Management Journal, 50*(1), 25–32.

Eriksson, P. E., Patel, P. C., Sjödin, D. R., Frishammar, J., & Parida, V. (2016). Managing interorganizational innovation projects: Mitigating the negative effects of equivocality through knowledge search strategies. *Long Range Planning, 49*(6), 691–705.

Filippou, D., & King, M. G. (2011). R&D prospects in the mining and metals industry. *Resources Policy, 36*(3), 276–284.

Frishammar, J., Florén, H., & Wincent, J. (2011). Beyond managing uncertainty: Insights from studying equivocality in the fuzzy front end of product and process innovation projects. *IEEE Transactions on Engineering Management, 58*(3), 551–563.

Gama, F., Sjödin, D. R., & Frishammar, J. (2017). Managing interorganizational technology development: Project management practices for market- and science-based partnerships. *Creativity and Innovation Management, 26*(2), 115–127. https://doi.org/10.1111/caim.12207.

Gopalakrishnan, S., Bierly, P., & Kessler, E. H. (1999). A reexamination of product and process innovations using a knowledge-based view. *Journal of High Technology Management Research, 10*(1), 147–166.

Grant, R. M. (1996). Toward a knowledge-based theory of the firm. *Strategic Management Journal, 17*(Special Issue), 109–122.

Grönroos, C. (2012). Conceptualising value co-creation: A journey to the 1970s and back to the future. *Journal of Marketing Management, 28*(13–14), 1520–1534. https://doi.org/10.1080/0267257X.2012.737357.

Grönroos, C., & Voima, P. (2013). Critical service logic: Making sense of value creation and co-creation. *Journal of the Academy of Marketing Science, 41*(2), 133–150.

Hutcheson, P., Pearson, A. W., & Ball, D. F. (1996). Sources of technical innovation in the network of companies providing chemical process plant and equipment. *Research Policy, 25*(1), 25–41.

Iansiti, M., & Lakhani, K. R. (2014). Digital Ubiquity: how connections, sensors, and data are revolutionizing business (digest summary). *Harvard Business Review, 92*(11), 91–99.

Iebra Aizpurúa, L., Zegarra Saldaña, P. E., & Zegarra Saldaña, A. (2011). Learning for sharing: An empirical analysis of organizational learning and knowledge sharing. *International Entrepreneurship and Management Journal, 7*(4), 509–518.

Keupp, M. M., Palmié, M., & Gassmann, O. (2012). The strategic management of innovation: A systematic review and paths for future research. *International Journal of Management Reviews, 14*(4), 367–390.

Kurkkio, M., Frishammar, J., & Lichtenthaler, U. (2011). Where process development begins: A multiple case study of front end activities in process firms. *Technovation, 31*(9), 490–504.

Lager, T. (2012). *Managing process innovation: From idea generation to implementation*. London: Imperial College Press.

Lager, T., & Frishammar, J. (2010). Equipment supplier/user collaboration in the process industries: In search of enhanced operating performance. *Journal of Manufacturing Technology Management, 21*(6), 698–720.

Lee, A. H. I., Wang, W. M., & Lin, T. Y. (2010). An evaluation framework for technology transfer of new equipment in high technology industry. *Technological Forecasting and Social Change, 77*(1), 135–150.

Lu, Q., & Botha, B. (2006). Process development: A theoretical framework. *International journal of production research, 44*(15), 2977–2996.

Mary George, N., Parida, V., Lahti, T., & Wincent, J. (2016). A systematic literature review of entrepreneurial opportunity recognition: Insights on influencing factors. *International Entrepreneurship and Management Journal, 12*(2), 309–350.

Milewski, S. K., Fernandes, K. J., & Mount, M. P. (2015). Exploring technological process innovation from a lifecycle perspective. *International Journal of Operations & Production Management, 35*(9), 1312–1331.

OECD. (2005). Oslo Manual. Guidelines for Collecting Data and Interpreting Innovation Data. Retrieved from Paris:

Parida, V., Burström, T., Visnjic, I., & Wincent, J. (2018). Migrating industrial ecosystems to a circular economy paradigm: A two-stage transformation process. *Journal of Business Research* In press.

Pisano, G. P. (1996). Learning-before-doing in the development of new process technology. *Research Policy, 25*(7), 1097–1119.

Porter, M. E., & Heppelmann, J. E. (2014). How smart, connected products are transforming competition. *Harvard Business Review, 92*(11), 11–64.

Reichstein, T., & Salter, A. (2006). Investigating the sources of process innovation among UK manufacturing firms. *Industrial and Corporate Change, 15*(4), 653–682.

Robertson, P., Smith, K., & Von Tunzelmann, N. (2009). Innovation in low-and medium-technology industries. *Research Policy, 38*(3), 441–446.

Robertson, P. L., Casali, G. L., & Jacobson, D. (2012). Managing open incremental process innovation: Absorptive capacity and distributed learning. *Research Policy, 41*(5), 822–832.

Rönnberg Sjödin, D. (2013). A lifecycle perspective on buyer-supplier collaboration in process development projects. *Journal of Manufacturing Technology Management, 24*(2), 235–256.

Rönnberg Sjödin, D., & Eriksson, P. E. (2010). Procurement procedures for supplier integration and open innovation in mature industries. *International Journal of Innovation Management, 14*(4), 655–682.

Rönnberg Sjödin, D., Eriksson, P. E., & Frishammar, J. (2011). Open innovation in process industries : A lifecycle perspective on development of process equipment. *International Journal of Technology Management, 56*(2/3/4), 225–239.

Rönnberg Sjödin, D., Frishammar, J., & Eriksson, P. E. (2016). Managing uncertainty and equivocality in joint process development projects. *Journal of Engineering and Technology Management, 39*, 13–25. https://doi.org/10.1016/j.jengtecman.2015.12.001.

Rönnberg Sjödin, D., Parida, V., & Lindström, J. (2017). Barriers and conditions of open operation: A customer perspective on value co-creation for integrated product-service solutions. *International Journal of Technology Marketing, 12*(1), 90–111.

Schuman, C. A., & Brent, A. C. (2005). Asset life cycle management: Towards improving physical asset performance in the process industry. *International Journal of Operations and Production Management, 25*(6), 566–579.

Sjödin, D.R., Parida, V., Leksell, M., and Petrovic, A. (2018) Smart factory implementation and process innovation: A preliminary maturity model for leveraging digitalization in manufacturing research. *Technology Management*, In press.

Skinner, W. (1992). The shareholders delight: Companies that achieve competitive advantage from process innovation. *International Journal of Technology Management, 7*(1/2/3), 41–48.

Stock, G. N., & Tatikonda, M. V. (2008). The joint influence of technology uncertainty and interorganizational interaction on external technology integration success. *Journal of Operations Management, 26*(1), 65–80.

Terjesen, S., & Patel, P. C. (2017). In search of process innovations: The role of search depth, search breadth, and the industry environment. *Journal of Management, 43*(5), 1421–1446.

Tushman, M. L., & Nadler, D. A. (1978). Information processing as an integrating concept in organizational design. *Academy of Management Review, 3*(3), 613–624.

Vargo, S. L., & Lusch, R. F. (2008). Service-dominant logic: Continuing the evolution. *Journal of the Academy of Marketing Science, 36*(1), 1–10.

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 Krogh, G., Netland, T., & Wörter, M. (2018). Winning with open process innovation. *MIT Sloan Management Review, 59*(2), 53–56.

West, J., & Bogers, M. (2014). Leveraging external sources of innovation: A review of research on open innovation. *Journal of Product Innovation Management, 31*(4), 814–831.

Yin, R. (2003). *Case study research: Design and methods*. Thousand Oaks: Sage Publications.

Zack, M. H. (2001). If managing knowledge is the solution, then what's the problem? Knowledge management and business model innovation, 16–36.