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Tzokas, N

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Authors:

Akbar, H. University of Liverpool

Baruch, Y. University of Southampton

Tzokas, N. Plymouth University

Abstract

Feedback loops are instrumental in the organizational knowledge creation (OKC) process across the highly uncertain and dynamic innovation's front-end. Therefore, managers should be aware of how these loops unfold, how to recognize meaningful patterns and how to steer them towards planned and emergent outcomes. Easy to say, difficult to practise! In this empirical paper, we focus on knowledge-conceptualization – the new knowledge's generation-crystallization journey – and develop a unique model of feedback loops as dynamic processes of OKC in the context of the innovations' front-end. Using 10 qualitatively studied innovations, we identify five front-end OKC stages (generation, evaluation, expansion, refinement and crystallization) and pattern these based on their overlaps to explore the associated feedback loops. Our model distinctively illustrates increasing-decreasing, diverging-converging and frequent negative-*cum*-positive loops, and illuminates the complex and rich patterns of loops not captured before.

Key Words: Feedback loops, Organizational knowledge creation, Front-end, Knowledge-conceptualization, Innovation process.

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Introduction

Innovations are entwined with organizational competitiveness (Ritala, 2012; Tregaskis et al., 2015). Critical to developing innovations is the front-end – involving an innovation's generation-crystallization journey (Poskela and Martinsuo, 2009) – because it determines if the innovation merits further investments by the organization (Cooper, 2008). Yet, the front-end is dynamic, i.e. evolving (Brentani and Reid, 2012), and its dynamics remains unclear (Frishammar et al., 2013). It is, therefore, an important context for firms aiming to develop competitive innovations to understand. As innovations are also the novel outcomes of knowledge creation (Quintane et al., 2011) the front-end can be understood in terms of organizational knowledge creation (OKC). OKC is the process of making available and amplifying knowledge created by individuals, as well as crystallizing and connecting it to an organization's knowledge system (Nonaka and von Krogh, 2009), e.g. skills, capabilities, expertise (Vlaisavljevic et al., 2015), systems and practices combined (Davenport and Prusak, 2003). OKC emphasizes co-construction, emergence, social context and learning (Nonaka, 1994), among others, and provides a robust theoretical basis to engage with the dynamic process of developing innovations in the context of the front-end.

We concentrate on an important mechanism in developing innovations and in creating new knowledge – the feedback loops. They are the recursive cycles of interactions over time (McCarthy et al., 2006). Feedback loops improve and refine innovations (Van de Ven et al., 2008), articulate new knowledge (Fischer, 2001) and synthesize the conflict, or tension, between creativity and translation or exploration and exploitation (see Nonaka et al., 2000). They are typically categorized as positive, i.e. reinforcing and amplifying, or negative, i.e. contradictory and correcting, loops (Sterman, 2001). Thus, we know a lot about the important role they perform. However, what we understand less is that along the process of developing innovations how do loops facilitate movement, how do they function, how do they evolve, how do they fluctuate, how do they vary and how do they differ, and the dynamic patterns, if any, in their characteristics, role and/or types. These patterns are not theorized by the existing models, e.g. the coupling model (Rothwell, 1994) or the chain-linked model (Kline and Rosenberg, 1986). These models use stages, i.e. the higher level conceptualizations, involving sets of tasks and activities, organized as a series of [managerially useful] steps to achieve the desired outcomes (Lin and Hsieh, 2011), and depict loops through arrows and cycles between different stages. However, their stages are linear, or sequential; a convenient but limited approach to model the complex dynamics of loops because stages overlap (Cooper, 2008; Schroeder et al., 1989). Illuminating the dynamic patterns of loops requires that the loops are modelled based on how stages overlap and then feedback into one another. This gap hitherto remains open, but is vital to bridge, given the importance of loops in developing innovations (Bouncken, 2011; Scarbrough et al., 2015), across the highly uncertain front-end (Bröring et al., 2006; Herstatt and Verworn, 2004).

In a recent article, Akbar and Tzokas (2013) identified five front-end, knowledge-conceptualization stages – generation, evaluation, expansion, refinement and crystallization – and suggested how they might overlap. However, they did not model the feedback loops based on the suggested overlaps. Following on from this work, we pattern these stages based on their overlaps and ask: *how do feedback loops contribute to developing innovations along the front-end OKC stages*? and *are there any evolving patterns of loops which could shape our theoretical* *and managerial understanding about their dynamics across the front-end*? These research questions also respond to the recent calls for a better understanding of the front-end (Frishammar et al., 2013) and the dynamic process of OKC (Von Krogh and Geilinger, 2014) in the context of innovations (Vlaisavljevic et al., 2015). Using 10 cases of qualitatively studied innovations via 40 semi-structured interviews we identify the five stages and pattern these in relation to one another to explore their feedbacks. Our aim is to develop a broad model of the feedback loops in the context of the innovations' front-end.

We offer a unique model which distinctively illustrates the front-end journey through increasing-decreasing, diverging-converging and frequent negative-*cum*-positive loops. These patterns shed new light on the loops' non-uniform but systematic dynamics not captured earlier, and on their varying types which blurs their negative-positive distinction in the study's context. Hereafter, we discuss our context, i.e. the front-end, followed by our theoretical basis, i.e. OKC. Next, we elaborate upon our focus, i.e. feedback loops, followed by the critical examination of their existing models to illustrate the gap. We then present our methodology, followed by the development of our model. Finally, we state our contribution, implications, boundary conditions and future research directions.

The context – innovations' front-end

Innovations are defined in different ways. We adopt a multi-disciplinary definition of innovation, a '…multi-stage process whereby organizations transform ideas into new/improved products, service or processes [and management innovations], in order to advance, compete and differentiate themselves successfully in their marketplace' (Baregheh et al., 2009, p. 1334). This definition not only regards innovation as a process as well as an outcome, but also encapsulates stages, nature, types, aim and the social context of innovations. Developing innovations within a social context, e.g. organization, makes the process interactive, involving a complex interplay among various actors, with partly common and partly conflicting interests (Fischer, 2001).

Critical to developing innovations is the front-end. The front-end involves an innovation's generation-crystallization journey, i.e. from its generation in the shape of an idea, or the most embryonic form of a product/service (Montoya-Weiss and O'Driscoll, 2000), through its screening, or evaluation, preliminary assessment, or market/technical feasibility, and definition, or delineating scope, to its crystallization, or translation into a concrete, or well-defined, concept (Cooper, 1983; Perry-Smith and Mannucci, 2015). The front-end is critical to developing innovations because it has the largest potential for improvements with the least effort possible (Brentani and Reid, 2012; Frishammar et al., 2013), and determines if the innovation is worthy of serious consideration and further investments (Cooper, 1983, 2008). The quality of planning at the front-end is crucial for project success and organizational performance (Khurana and Rosenthal, 1997; Poskela and Martinsuo, 2009). Yet, the front-end is less structured and formalized, and highly uncertain (Brentani and Reid, 2012), making it difficult to manage (Cooper, 2008). It is also highly dynamic (Khurana and Rosenthal, 1997), and its dynamics is not clearly understood (Carlsson-Wall and Kraus, 2015; Frishammar et al., 2013). One way of understanding its dynamics is the process of OKC, as elaborated upon below.

Theoretical basis – organizational knowledge creation

OKC is widely regarded as a dynamic and interactive (or shared) process (Su et al., 2016; Leonard-Barton, 1995; Leonard and Sensiper, 1998). It aims to create worthwhile, or useful, organizational knowledge (Nonaka, 1994); one reflection of which are the innovations; others include, e.g. learning, meaning-making and shared understanding. OKC represents a process of construction (sense-making), where new knowledge is built (e.g. developed and shaped), depending upon the situation and on the interpretations of the members of the social context (Nonaka and Takeuchi, 1995). OKC, therefore, follows the *logic of appropriateness*, i.e. situation-driven response, evolving through socialization and discovery, which contrasts with the *consequential logic*, i.e. preference-driven behaviour, underpinning the traditional approach to developing innovations. While the traditional approach emphasises a stable sequence of steps (e.g. stages and associated activities), OKC emphasises contingency. Thus, for example, testing and design activities, which are typically sequenced post front-end, could be a part of the OKC's front-end crystallization as an (initial) attempt to test the concept's applicability and reliability (see Nonaka, 1994). Similarly, while the traditional approach regards conflict as a 'disturbance', or disruption, OKC considers it as necessary to generate reflection and new meaning, and, therefore, needs to be encouraged (Nonaka, 1991). OKC's approach resonates well with the view of innovations as constructed phenomena (Coopey et al., 1997; Damanpour and Schneider, 2006). It also emphasizes co-construction, emergence and learning and, therefore, provides a robust theoretical basis to engage with the dynamic process of developing innovations.

OKC also shares similarities with the front-end. Just like OKC, the process of developing of innovations across the front-end is regarded as a constructed process (Oliveira et al., 2015).

The front-end typically starts with the generation of an innovation idea, which is then developed, defined and crystallized. Similarly, OKC starts with the knowledge generated by individuals (e.g. an innovation idea), which is then amplified (expanded), refined (improved/pruned), and crystallized (shaped/formed) at the group level, in addition to being connected (fitted or aligned) with the organizational context, e.g. objectives, constraints (Nonaka and von Krogh, 2009), customers and market. Given these similarities, we use OKC as the theoretical basis to understand the dynamics of the front-end. We concentrate on an important mechanism in developing innovations and in creating new knowledge, as explained below.

Feedback loops

Feedback loops are the recursive, i.e. repeated and iterative (Günzel and Holm, 2013), cycles of interactions (McCarthy et al., 2006), originating from the individual and collective contributions over time. They play an important role in improving and refining innovations (Cheng and Van de Ven, 1996), and in learning, reflection and articulating new knowledge (Fischer, 2001). They also synthesize the conflict between creativity and translation (see Nonaka et al., 2000), and between divergent and convergent activities (Van de Ven et al., 2008). Feedback loops also mitigate the conflict between exploration and exploitation, such as when the ambitious (or unrealistic) ideas fed forward by the former are made practical (or doable) by the latter feeding back to them (see Crossan et al., 1999). In the context of innovation adoption, loops are typically categorized as positive, i.e. reinforcing, stimulating or amplifying, and negative, i.e. counteracting, correcting and limiting (Sterman, 2001). The former progress change, whereas the latter oppose change (McCarthy et al., 2006), although the creativity literature suggests that even the latter, if constructive, could be stimulating: '…the bad news is as important to furthering the creative process as is the good' (Leonard and Swap, 1999, p. 168). Thus, we know a lot about the characteristics, role and types of loops. We also have suggestions that their types vary in strength and direction over time (Cheng and Van de Ven, 1996). However, what we understand less is that along the process of developing innovations how do the loops function to facilitate movement, how do their characteristics evolve and fluctuate, how do their types vary and differ, and what dynamic patterns, if any, do they reflect in their characteristics, role and/or types.

The dynamic patterns of loops are not theorized by the existing models. One set of models highlight loops at the user-manufacturer interface (Von Hippel, 1994) or the technology and user environment interface (Leonard-Barton, 1988). Cooper's (2008) analysis of stage-gates identifies loops between customers or users and different stages (business-case, development and testing). Other models incorporate loops between different stages. For example, the third-generation coupling model incorporates feedbacks between different sets of adjacent stages (generation, research/design/development and archetype production) (Rothwell, 1994). Similar is the Berkhout and Hartmann's (2006) cyclic innovation model showing scientific research, technological research, product development and market transitions stages. Kline and Rosenberg's (1986) chain-linked model (later adapted by Fischer, 2001; Myers and Rosenbloom, 1996) uses arrows to depict feedbacks between different sets of adjacent or non-adjacent stages (potential-market, invent/produce analytical design, detailed design/testing, redesign/produce, distribute/market), and superimposes recursive cycles between different *succeeding* and *preceding* stages. While these models cover the entire innovation process and not the front-end in-depth, they usefully highlight the 'somewhat' disorderly nature of the innovation process. However, they adopt an overarching linear approach and reflect sequential stages; a convenient but limited approach to capture the complex dynamics of loops. The innovation process is not smooth or well-behaved and does not involve a linear or fixed pattern/sequence of stages (Schroeder et al., 1989), and its stages overlap and run parallel to each other (Cooper, 2008). For Damanpour and Schneider (2006), it involves a linear as well as a multiple sequence pattern. As a result, these models illuminate little the dynamic patterns of loops. Capturing these patterns requires that the loops are modelled based on how stages overlap and then feedback into one another. This gap hitherto remains unaddressed.

More recently, Akbar and Tzokas (2013), in patterning the OKC's building-blocks (individuals and teams, levels and types of knowledge, and social interactions), identified five front-end, knowledge-conceptualization stages – generation, evaluation, expansion, refinement and crystallization (including its differentiation and integration sub-stages) – and suggested how they might overlap. They suggested that while evaluation overlaps with generation and expansion, and crystallization overlaps with expansion, the overlaps are profound between refinement and expansion. They, however, did not model the feedback loops based on the suggested overlaps. We pattern these stages based on their overlaps and, with the aim of developing a broad model of the front-end feedback loops, ask the following research questions:

- *how do feedback loops contribute to developing innovations along the front-end OKC stages*? and

- *are there any evolving patterns of loops which could shape our theoretical and managerial understanding about their dynamics across the front-end*?

Research Method, Contexts and Data

Approach and methods

Our research questions required an exploratory approach. We adopted a qualitative methodology, using semi-structured interviews. Our unit of analysis was the innovation at its front-end phase. In each case, we collected data from participants, and the individual, team and organizational level insights emerged in the discussion; thus reflecting the multidimensional considerations underpinning the relevant innovation. We could not use ethnography (or lived experience) because the innovations we studied (henceforth referred to as projects) often involved sensitive (e.g. patent-related) information, making access difficult *pre*-project completion. We, therefore, collected data based on reconstructed events, an approach which other studies have also used (Bosch-Sijtsema et al., 2011; Orlikowski, 2002). We asked informants from where the knowledge originated; how it was taken forward; how it was developed and crystallized; and how it was translated into a concrete concept (what form), with follow-up questions on the related processes, interactions, activities, aims, events and outcomes within these. To ensure the accuracy of reconstructions, we followed the within-method triangulation, or using multiple techniques within a method (Jick, 1979), in that we asked similar questions within (and across) projects and repeated key questions to ascertain the credibility and trustworthiness of the information. We cross-corroborated almost half of the information gathered; a credible criterion (Merriam, 2009).

Research projects

Our aim was to develop a broad model of feedback loops. We thus remained flexible with regard to the nature of the firm or industry. We studied 10 innovative projects as detailed in Table 1. Innovative projects involve a high degree of newness and associated effort by those involved (see Cooper, 2008) and, therefore, allowed for rich data and easier recall of events. We selected projects which had won an award or had gained wide media publicity. Their innovativeness was further ascertained from initial discussions with the informants. We continued recruiting projects until saturation, where additional interviews no longer discovered anything new or disputed existing relationships (Strauss, 1987).

Table 1: Description of Innovations and their Contexts

Project	Organizational Context	Employees	Nature of Innovations/Salient Details	Team Size (interviews)
Project 1	A UK county's government and the largest employer in the region. It provides services, including libraries, adult social services, schools, highway maintenance and waste disposal.	Over 25,000 (70 per cent full-time).	An innovative ICT project to provide internet access to the public and linking 49 libraries across a UK county. The project was not just difficult compared to the existing skills/competencies, but also required a complete cultural change in the way librarians traditionally functioned.	5 members (9 interviews)
Project 2	Small-sized (now) biotechnology public limited company, providing health care solutions, particularly for allergies.	8 scientists and staff	A research-based, new to the biotechnology market product, enjoying two 20-year patents – one each for the chemistry and delivery device – the latter being its USP. The innovation offers allergy sufferers a novel user-friendly dust-mites test, significantly different from existing market products.	2 members (2 interviews)
Project 3	An autonomous, international research institution in plant science/microbiology. It is supported by 40 private organizations, the European Union and the UK Government.	950 (800 scientists and researchers)	An innovative idea which genetically modifies grass to grow to a defined height. Based on the institution's existing patent, it won the UK Biotechnology and Biological Science Research Council's Young Entrepreneurs Scheme Award for its potential application to the multi-billion-dollar golf-course industry world-wide.	4 members (4 interviews)
Project 4	A leading autonomous research institution, offering multidisciplinary research on food safety, diet/health, and food materials. It is supported by the UK Government and the European Union.	215 research and support staff	An innovative idea which uses probiotic (friendly) bacteria to target MRSA ('superbug') and poultry respiratory tract infections – together representing $4.5 billion market. The product won the UK Biotechnology and Biological Science Research Council's Young Entrepreneurs' Scheme Award.	4 members (5 interviews)
Project 5	The research organization of a blue-chip computer firm. It conducts basic and applied research in computer science and software engineering.	Over 100 researchers	A creative marketing strategy, involving annual lectures (on computer development, artificial intelligence, visual perception, social media spaces, and network gaming). It targets teachers/students from Cambridge's sixth-form colleges to raise computer awareness and generate customer loyalty. The strategy was adopted within the world-wide organizational network.	4 members (5 interviews)
Project 6	A blue-chip public limited company, and a leading UK food production and retail firm.	Around 180,000	An innovative product range, representing a major deviation from the existing products. It involves quick, easy-to-cook and diversified meals for a £35 million industry, growing annually by 15 per cent.	3 members (3 interviews)
Project 7	A research institution affiliated with a world-class university, conducting fundamental biotechnical and biomedical research.	392 researchers and staff	A breakthrough chance-discovery on how one particular (Bcl-xL or cancer protection) gene is modified to cause tumor, which was published in Cancer Cell (prestigious refereed journal).	3 members (3 interviews)
Project 8	A part of Europe's largest manufacturers/processors of meat products. It supplies food services to reputed UK supermarkets.	Over 2,600 staff	An innovative easy-to-cook microwaveable range of bacon-based food products with a launch cost of £ 2-3 million. The product was significantly different from the organization's existing products.	3 members (2 interviews)
Project 9	A centre of excellence (29 Nobel Prizes) of a world-class university. The centre conducts research in basic/applied Physics.	Over 700 researchers and staff	A breakthrough chance-discovery which is likely to replace the $100 billion LCD (liquid crystal display) industry. It enjoys a 20-year patent, and has won the European Union's Descartes Prize.	3 members (3 interviews)
Project 10	Computer department of a renowned UK university. Conducts research and teaching in computer sciences and business electronics.	Over 3,000 researchers and staff	An innovative research-based project which uses virtual human (Avatar) technology for motion capture and sign language translation. It won The Royal Television Society and British Computer Society awards.	3 members (3 interviews)

Our projects represented diverse settings, which served our aim of developing a broad model of feedback loops. Most projects were conceptualized over a six- to eight-month period. Two projects (projects 2 and 8) were eventually unsuccessful for reasons other than those related to the OKC process. One organization was small-sized (0-9 employees), two were medium-sized (50-249 employees), and the remaining were large firms (more than 250 employees). Informants were mostly aged between 30 and 50 (77 per cent), male (61 per cent), and senior and middle managers (78 per cent), with differentiated expertise within or across disciplines.

Data collection and analysis

We conducted 40 semi-structured interviews. Our informants were the projects' team members, as shown in Table 1. Four informants were interviewed again to gather additional information as our understanding improved during the initial stages of data analysis. We took field notes (107 pages), and transcribed interviews (488 pages) which informants subsequently validated. To develop organizational and project contexts, we also collected information from organizational websites, annual reports, corporate plans, press releases, newsletters and project-related material.

For data analysis, and as recommended by Strauss (1987), we first conducted open coding through line-by-line inductive analysis. Here we looked at aims, processes, activities and outcomes. We generated 618 free nodes in this process, of which 529 were related specifically to processes, activities and interactions. We then identified five OKC stages as core categories based on what various processes/activities were aimed at and/or resulted in, and each stage was validated with other responses. The categories were labeled as knowledge-generation, knowledge-evaluation, knowledge-expansion, knowledge-refinement and knowledge-crystallization. We then used these stages to slice the data through an iterative process and constant comparison of categories. We categorized the 529 nodes under 66 codes under these five stages, as shown in Table 2. Table 2 not only cross-validates the stages, but also details the plurality of processes/activities employed by the firms.

Table 2: Processes/Activities involved in Knowledge-conceptualization Stages

Description *[Individual Interaction (I); Team/Group Interactions (G)]*	**Project 1**	**Project 2**	**Project 3**	**Project 4**	**Project 5**	**Project 6**	**Project 7**	**Project 8**	**Project 9**	**Project 10**
Knowledge-generation Stage - Processes/activities through which new knowledge was generated										
Using existing or previous knowledge (I)					✓	✓		✓		✓
Thinking creatively ('outside the box') (I)			✓	✓				✓		
Searching information (I)				✓		✓		✓		
Chance discovery (I)				✓			✓		✓	
Interacting with the environment (I)			✓	✓						
Interacting with an artifact (I)		✓						✓		
Generating analogies (I)				✓		✓				
Conducting needs analysis (I)				✓	✓					
Experimenting (I)						✓				
Using previous market research (I)								✓		
Capturing opportunity from legislation (I)										✓
Capturing opportunity from external document (I)	✓									
Interacting with the market/customers/suppliers (G)						✓		✓		
Using formal or informal team brainstorming (G)			✓	✓						
Seeking external expertise/knowledge/advice (G)						✓				
Interacting within collaborative networks (G)	✓									
Observing/imitating (G)	✓									
Knowledge-evaluation Stage - Processes/activities through which new knowledge was assessed and selected										
Obtaining feedback from colleagues (G)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Assessing the fit with organizational objectives (G)	✓				✓			✓		✓
Assessing the fit with market/customer needs (G)			✓	✓				✓		
Funneling/screening/short-listing ideas (G)				✓		✓	✓			
Assessing the fit with existing competencies (G)			✓	✓						
Assessing the fit with practicality/implementation (G)		✓								✓
Comparing with a benchmark or standard (G)	✓			✓						
Seeking external expertise/advice (G)		✓				✓				
Seeking internal expertise/advice (G)			✓	✓						
Obtaining feedback from friends/relations (G)			✓							
Assessing the fit with available resources (G)	✓									
Assessing the fit with intellectual curiosity (G)									✓	
Conducting cost-benefit analysis (pros and cons) (G)				✓						
Using logic (G)	✓						✓			
Displaying personal passion (G/I)			✓					✓		
Searching information (I)		✓	✓	✓						
Using gut feeling for intuitive appeal (I)				✓		✓				
Assessing the fit with existing product categories (I)								✓		

Description *[Individual Interaction (I); Team/Group Interactions (G)]*	**Project 1**	**Project 2**	**Project 3**	**Project 4**	**Project 5**	**Project 6**	**Project 7**	**Project 8**	**Project 9**	**Project 10**
Testing and experimenting (I)							✓			
Visualizing future potential (I)										✓
Knowledge-expansion Stage - Processes/activities through which new knowledge was amplified										
Employing formal/informal team brainstorming (G)	✓		✓	✓	✓			✓	✓	
Seeking internal expertise/advice/inputs (G)	✓			✓		✓	✓		✓	
Interacting generally within the organization (G)	✓						✓		✓	✓
Interacting with market and customers (G)			✓			✓				
Seeking external expertise/advice (G)		✓								✓
Learning from external explicit knowledge (G)							✓			
Learning from experiences of colleagues/others (G)			✓			✓				
Learning from previous adverse experiences (G)	✓									
Learning from a chance event (e.g. regulation) (I)		✓		✓						
Searching information (I)			✓							
Using previous experience and expertise (I)		✓								
Interacting with a physical artifact (I)	✓									
Knowledge-refinement Stage - Processes/activities through which new knowledge was made workable and deliverable										
Meeting with team on implementation details (G)	✓		✓	✓	✓			✓	✓	✓
Seeking external expertise/advice (G)		✓	✓	✓		✓		✓		✓
Seeking internal expertise/advice (G)			✓	✓		✓	✓	✓	✓	
Assigning roles/tasks to team members (G)	✓		✓	✓						
Using prior knowledge (G)									✓	✓
Adapting existing technologies (G)										✓
Involving users (G)	✓									
Using a trial-and-error approach (G/I)	✓						✓			✓
Testing/ prototyping/experimenting (I)		✓				✓		✓	✓	
Searching/acquiring information (I)			✓	✓						
Knowledge-crystallization Stage - Processes/activities through which new knowledge was translated into a concrete concept										
Differentiation - Breaking new knowledge into specialized parts										
Assigning specialized tasks to team members (G)	✓		✓	✓	✓	✓	✓	✓	✓	✓
Seeking/learning from external expertise/advice (G)		✓	✓					✓	✓	
Discussing/obtaining feedback in team meetings (G)	✓		✓	✓				✓		
Seeking internal expertise/advice (G)	✓			✓						
Team members' working on assigned parts	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Integration - Bringing specialized parts of new knowledge into a coherent whole										
Seeking internal expertise/advice (G)		✓		✓						
Using managerial skills of an individual (I)	✓		✓	✓		✓	✓	✓	✓	✓

The identification of patterns was an iterative process, and involved three main steps. Firstly, we identified the patterns of interactions within a stage; this was to provide greater depth to the stages. Secondly, we focussed on patterning stages in relation to each other. This posed challenges because stages emerged as overlapping conceptualizations rather than discrete and separate entities. Yet, they also appeared sequential as well as parallel. We thus adopted a step-by-step approach to analyze one stage at a time in relation to another. We patterned stages based on their conflicts, and also classified them under the creative and translation dimensions (as higher-order categories); the former involving generation and expansion stages, and the latter involving evaluation, refinement and crystallization stages. Finally, we focused on how the translation stages fed *back* into those in the creative stages. A feedback occurred when discussions and insights from a particular translation stage made team members reflect upon existing ideas and/or generate new ones. We did not find the refinement and crystallization stages feeding back into the generation stage perhaps because of the temporal distance between them. Thus, we analyzed four sets of feedbacks: from evaluation to generation, from evaluation to expansion, from refinement to expansion, and from crystallization to expansion. With the exception of one project with uniformly distributed feedbacks, all other projects showed a similar pattern – non-existent/low initial feedbacks, increasing later, and reducing or becoming non-existent at the end. Thus, we analyzed the feedbacks collectively. The dynamic patterns were emergently identified from comparing categories and pattern-matching as well as data displays, validating each pattern with other responses (Eisenhardt, 1989).

Using the standard cross-case analysis techniques (e.g. Eisenhardt, 1989), we also conducted cross-project analysis to look for similarities and differences in patterns through comparison of categories. The five stages were common to all projects and, in spite of the plurality of processes/activities used, the substantive nature of each stage remained valid across all projects. Most projects showed similar patterns of interactions between and across stages. The major differences identified were that customer/market interactions were predominant in business compared to research organizations, and that the latter employed more formal methods of evaluating/refining new knowledge compared to the former. Our findings are presented below.

Developing a dynamic model of the front-end loops

Knowledge-conceptualization stages

Knowledge-conceptualization started with the generation of knowledge in the shape of an idea (or ideas), or the *knowledge-generation stage.* As highlighted in Table 2, this stage involved varied processes and activities – chance discoveries, creative processes (e.g. 'thinking outside the box' and generating analogies) as well as structured/methodical processes (e.g. experimentation and needs analysis). Ideas predominantly originated from individuals: *"I had been aware of the Christ lectures held by the Royal Institute for quite some time. They were very much embedded somewhere back in my mind"*, and *"… I picked up the gap in the way we functioned that we need to interact more with our local environment in terms of outreach and education and then at a spur of the moment, the Royal Institute thing just came as a flash"* (Project 5, Interview 2). This predominant individual-interactive pattern was also corroborated across projects because Table 2 highlights that an individual's existing/previous knowledge was the most frequent process, whereas seeking external expertise, network interactions and observing/imitating others were the least frequent processes. Table 2 also suggests that the diversity of the processes employed was not related to the project's nature. For example, a research-based discovery (Project 7) and two research-based product technologies (projects 2 and 9) involved less diverse processes, whereas another research-based product technology (Project 4) involved more diverse processes (and so did the manufacturing-based product innovations (projects 6 and 8) as well).

Next was the *knowledge-evaluation stage* where the knowledge generated above was analyzed and assessed for its potential. As highlighted in Table 2, this stage also involved varied processes and activities – structured/methodical processes (e.g. cost-benefit analysis, funneling/screening/short-listing and comparison against a benchmark) as well as intuitive processes (e.g. 'gut feeling' and personal passion). Evaluation was mainly done via team interactions: *"It was quite demoralizing at the beginning…they come with all these ideas and at the end of the meeting we go, oh, right, we don't like any of those. And then we'd go away and think about it again…"* (Project 4, Interview 3). This predominant team-interactive pattern was also corroborated across projects because Table 2 highlights that feedback from colleagues was the most frequent process, whereas individuals conducting test experiment and visualizing the new knowledge's future potential were the least frequent processes. Table 2 also suggests that the diversity of the processes employed was not related to the project's nature. For example, research-based product technologies (projects 3 and 4) involved more diverse processes, whereas another such technology (Project 9) involved less diverse processes (and so did the management innovation (Project 5) as well). The knowledge here was also connected broadly with the organizational context: *"[whether or not to develop it further]…was a fairly early decision, that that was a logical thing. It fitted in roughly with the amount of money that we had and with the organizational objectives at the time"* (Project 1, Interview 6).

Next was the *knowledge-expansion stage* where the knowledge was amplified, or expanded. For example, *"…it was like, oh we can do a short grass…football pitches…golf course…flowering regulations…switch technology…service arm, and it just kind of grew and grew and grew, like that"* (Project 3, Interview 4). This expansion did not fundamentally revise the original idea, but only added new features and applications. As highlighted in Table 2, this stage involved varied processes and activities – creative processes (e.g. team brainstorming) and learning processes (e.g. from customers, others' experiences, and internal/external experts). This stage was mainly team-interactive: *"…all of the dimensional aspects [applications]…came out as we were developing it [together]…I wouldn't say that any one person put more into any one of those, or came up with more of those ideas than anyone else"* (Project 3, Interview 3). This predominant team-interactive pattern was also corroborated across projects because Table 2 highlights that individuals using previous experience/expertise, searching information or interacting with a physical artefact, were the least frequent processes. Table 2 also suggests that the diversity of the processes employed was not related to the project's nature. For example, just like the service-based technology (Project 1), a research-based product technology (Project 3) involved more diverse processes, whereas another research-based product technology (Project 10) did not. Similarly, just like the management innovation (Project 5), a manufacturing-based product innovation (Project 8) involved less diverse processes, whereas another manufacturing-based product innovation (Project 6) did not.

Also emerged from the analysis was the *knowledge-refinement stage* where the knowledge was improved and pruned. For example, *"[signs were]…recorded and could be played back…that led to this idea…we could synthesize or construct a sentence…that meant…that this need for a notation like Hamsys wasn't actually necessary"* (Project 10, Interview 2). As highlighted in Table 2, this stage involved varied processes and activities – structured/methodical processes (e.g. testing/prototyping/experimenting and searching/acquiring information) as well as shared processes (e.g. team meetings and internal/external interactions). These worked on the specific details of knowledge to make it practically implementable, i.e. workable and deliverable. This stage was predominantly team-interactive: *"[what] YY brought to the table was a very raw idea… And then it was a combination of a lot of team talking, that we actually narrowed our product down to what we have it as today"* (Project 4, Interview 1). Teams also interacted within and outside the organization. This predominant team-interactive pattern was also corroborated across projects because Table 2 highlights that team meetings was the most frequent process, whereas an individual searching/acquiring information was the least frequent process. Table 2 also suggests that the diversity of the processes employed was perhaps related to the project's nature. For example, research-based product technologies (projects 3, 4 and 10) involved more diverse processes, whereas the management innovation (Project 5) involved least diverse processes. The knowledge here was also connected specifically with the organizational resources and capabilities, and operational constraints: *"...we'd been talking to manufacturers. Because it was important to get their feedback…to say this is impossible to manufacture… So there was also feed-forward and getting information back to make sure that things that we were developing were manufacturable"* (Project 2, Interview 2).

As a result of the above, the knowledge started taking shape. Here, two sub-stages emerged; firstly, the knowledge was broken down into smaller specialized parts (or components) for detailed work/attention – or *differentiation*, and subsequently, the independent parts were merged into a coherent whole – or *integration*. These sub-stages occurred closer together because they were typically mentioned in a single response. Together these two sub-stages represented the *knowledge-crystallization stage* because they shaped and formed knowledge into a concrete and explicit form. As shown in Table 2, differentiation involved a combination of individual and team processes. Firstly, individual team members with specialized skills worked on their assigned parts: *"...different people wrote different sections of the bid, so they know it…the library system itself is so complex that there is no one person who has the full picture…"* (Project 1, Interview 3). These parts were repeatedly brought back to the team: *"So we all did our individual bits of research and came back [to the team]…with a group of slides that we would use to explain our particular piece of research…to each other about our little bit"* (Project 3, Interview 3). Teams also interacted within and outside the organization. Table 2 suggests that this individual- and team-interactive pattern was shared by all projects. It also suggests that the diversity of the processes employed was not related to the project's nature. For example, just like the service-based technology (Project 1), a manufacturing-based product innovation (Project 8) and research-based product technologies (projects 3 and 4) involved relatively more diverse processes than similar other projects. Interestingly, during integration, an individual manager or leader kept the team focussed on the end-product and the deadlines, and oversaw the integration of knowledge, a pattern shared by almost all projects: *"…when we got BB…she kind of played, someone would have called the 'nannying role' and making sure that if we'd been given a job to do, we actually did deliver it on time, and keeping us all together…."*, and *"...get this job done"* (Project 1, Interview 5).

Having identified the knowledge-conceptualization stages, the next step is to pattern these stages in relation to each other.

Patterning knowledge-conceptualization stages

We noticed early on in our analysis and field notes that the knowledge (generated by individuals) was often ambitious, or unrealistic. This led to a conflict, or tension, with the need to make it practical, or doable. This conflict firstly emerged between the generation and evaluation stages:

> *…EE had these wonderful ideas about what could happen in the future…but they were perhaps a bit too highfalutin for the amount of money that was being offered and what we could realistically implement within the period in which we had to spend the money* (Project 1, Interview 2).

This conflict was synthesized from interactions: *"…a lot of the dialogue initially was about the ideas, and getting a good idea and streamlining that idea and looking at the pitfalls in the idea…"* (Project 3, Interview 4). These interactions were evident across all projects, suggesting that the generation and evaluation stages overlapped. To reflect their conflict, we positioned these stages opposite to each other. Yet, we also patterned them partly across each other because sequentially the evaluation stage followed the generation stage and would not have occurred had the knowledge not been generated.

Secondly, conflict emerged between the expansion and refinement stages. This conflict was often volatile and occurred when aligning the unrealistic features and applications of knowledge with the specific organizational operations and resource constraints:

> *Because I have been trying to pull it down to practical, and say, don't add anything. You think it is an attribute, I think it is another process that would cost us money, and although I will do it, you'd better be costing this…* (Project 8, Interview 2).

This conflict was also resolved from interactions: *"…other parts of dialogue were on, sort of, mechanics of what we are going to do and how we are going to do that…yes, we buy the patent pack, but how would we deal beyond that"* (Project 9, Interview 2). These interactions were invariable across all projects. This suggested that the expansion and refinement stages overlapped and ran parallel to each other. To reflect their conflict, we positioned these two stages opposite to each other. Yet, we also patterned them partly across each other because sequentially the refinement stage followed the expansion stage and would not have occurred had the knowledge not been expanded.

The expansion of knowledge continued well into the crystallization stage. For example, *"…a lot of the ideas, for example, we generated when we sat down together to draft a specification for the patent…"* (Project 9, Interview 1). This suggested that the expansion and crystallization stages overlapped, and that this pattern was shared by most projects. However, an interesting type of conflict arose when the ongoing expansion of knowledge conflicted with the pressing need to advance knowledge to fruition:

> *…because we were having these meetings which were very unstructured which was great for getting ideas and creativity going. But at some point we did need organising to some extent… So, we needed somebody new to come in and impose a structure on us* (Project 1, Interview 4).

This conflict was not synthesized from interactions *per se*. Instead, it was synthesized from a deliberate attempt to control interactions which then paved the way for the integration of knowledge:

> *I was called really quite towards the end. It had been going for a while before I was called in. I was called in by one of the assistant directors. Because he felt that they were full of ideas, but weren't actually moving forward. They were continually discussing new ideas, sort of going up and up on their own fancies and so on, but there wasn't anybody amongst them who perhaps was making them come to a conclusion. And, I was seen as somebody who was, as I said to you before, I was more the sort of, let's get this job done* (Project 1, Interview 5).

To reflect the conflict between the expansion and crystallization stages, we positioned them opposite to each other. Yet, we also patterned them partly across each other because sequentially the integration sub-stage followed the expansion stage to restrict the otherwise unending expansion of knowledge.

Having identified how the stages are patterned in relation to each other, we now turn to the patterns of feedback loops across these stages.

Feedback loops across the knowledge-conceptualization stages

Knowledge, following its generation, was made available to the team for evaluation. However, at times, the knowledge was not regarded as exciting or pragmatic, and this information was fed back to the generation stage:

> *One idea was to use…probiotics… So we thought that was a pretty good product actually. And then…we spoke to a guy that works at MMM…the company is set up to commercialize science. He said, well, it is all right [okay, but not exciting], but go away and continue thinking* (Project 4, Interview 2).

We identified three (3) such instances of feedbacks (see Table 3 for other examples). This suggested that the evaluation and generation stages often involve recursive loops. Interestingly, and as shown in Table 3, these loops could not be categorized as either negative or positive, but represented a negative-*cum*-positive combination: *YY came up with the original idea…Well, my thought was…but you're never going to get away with spraying Staph Aureus [negative loop]. So why don't you put probiotics in there instead [positive loop]* (Project 4, Interview 2). These loops continued until one idea was considered worthy of further development.

Table 3: Representative Examples of Feedback Loops between the Knowledge-conceptualization Stages

Feedbacks from the evaluation stage to the generation stage
- ***Negative-cum-positive loop:*** *And we sat one lunchtime, just to discuss [evaluate] the ideas. And we, we very quickly dismissed all 5 ideas [negative loop]...but doing that actually was a good thing, because it, it showed the team that we could bring any idea to the team, no matter how ridiculous, and discuss it, and not be embarrassed to do that. And as soon as I did that, then other people started bringing ideas forward [positive loop]…* (Project 4, Interview 1). - ***Negative-cum-positive loop:*** *YY came up with the original idea. She said wouldn't it be good to be able to spray Staphylococcus Aureus which was pathogenic to stop therefore the pathogenic Staph Aureus binding. Well, my thought was that that's fantastic idea but you're never going to get away with spraying Staph Aureus [negative loop]. So why don't you put probiotics in there instead [positive loop]. So, that was the way really that whole product came from* (Project 4, Interview 2).
Feedbacks from the evaluation stage to the expansion stage
- ***Positive loop:*** *I went to look at patents in grass, you know, what was out there already, what different, how much the lawn mowing industry was worth….Well, we were thinking worldwide more or less immediately. Mainly again because of the GM thing, because we knew it was more accepted in other countries. And then we realised that the leisure market is more developed in other countries as well, namely the US and Japan* (Project 3, Interview 2). - ***Positive loop:****…[while evaluating] he did also give us the information that we didn't have…we hadn't thought about marketability…also potential income we were going to get …He also talked, talked us through how a product had to meet customer needs…he made us look for a product from a different angle…* (Project 4, Interview 1). - ***Positive loop:****…you share ideas with people…discuss what you're doing…and they say well let's look at putting that in sandwiches, because if it's a trend in salad dressings, it's going to go and be a trend in sandwich filling* (Project 8, Interview 3).
Feedbacks from the refinement stage to the expansion stage
- ***Negative-cum-positive loop:*** *So we worked quite closely with, one of our XXX Partners and the young woman's project at YYY…[during testing] they looked at it and said 'well that's a load of old rubbish, that's not how we would access it [negative loop], we need it to be more perhaps little icons of things [positive loop] rather than the words' that being librarians we use* (Project 1, Interview 5). - ***Negative-cum-positive loop:*** *Well, we had some idea of how to do what it was going to work…But as I said once we went to external design companies [to explore manufacturability], they developed further, because then they had ideas from designers, to design real devices [positive loop]. Again bit of creativity came from that. So we, our initial thoughts were completely different to what they saw for the product [negative loop]* (Project 2, Interview 2). - ***Negative-cum-positive loop:*** *…we think about…How can we control flower…If it flower[s], two problems, one is it had gene escape danger, second… they have this kind of thing grown up in stem…So it practically doesn't work [negative loop]…So we have to think about a control for no flow…[positive loop]* (Project 3, Interview 1). - ***Negative-cum-positive loop*****:** *He suddenly came along and said, actually, can you not use this technology outside of the humans, i.e. in an animal [negative loop]. And he said that he'd recently read the regulation where they were cutting down antibiotics in foods, of animals, particularly, animal feed…So he said why can't you use the same technology in chickens [positive loop], and that was great, that was fantastic, because that provides us with a new direction (Project 4, Interview 1).* - ***Negative-cum-positive loop*****:** *On this range, I had a rocket pesto…and there was a food safety issue…some sort of contaminations…there's a perceived risk…get some cross-over bacteria. And someone who's very technical, right at that stage said no, that's it, we're not launching this product [negative loop]. But my idea was to think laterally about it, think well turn it into a sauce then, if you put it in a sauce then it can go in the oven, so add some cream to it…[positive loop] (Project 6, Interview 2)* - ***Positive loop:*** *Marketing would cost the promotion…And then they would ring me up and would say how can we improve this, how can we get this product cheaper. They looked at raw material, they ask my opinions, we would look at raw material, we could have a cheaper raw material, perhaps with more fat on it…* (Project 8, Interview 2). - ***Positive loop:****…part of the process was to try and define what was needed for application and we were looking at this 1% as the target figure to set for the performance. We then did start looking at bench marking the polymer LED against the small molecule LED, which is the Kodak developed area, looking at what they do, what are the ideas that have been put into that area, can we implement similar or better things with polymers…* (Project 9, Interview 3).
Feedbacks from the crystallization stage to the expansion stage
- ***Positive loop:****…we submitted that paper to Cancer Cell. It got refereed, they sensed it is all very nice. They had some other suggestions. They wanted some more experiments to be done on something actually to do with chromosomal analysis, and so on* (Project 7, Interview 2). **- *Positive loop:*** *…we already got a lot of ideas, yes, we are now sort of pushing them in on to piece of paper, but in that process, other ideas were coming up. And that's actually quite a nice way of doing it. You know, say what we could have done said, right, one of us will write a draft, then rest of us all critique it. And that wouldn't nearly as fruitful as that we sat around together and wrote the draft together* (Project 9, Interview 2).

The knowledge was then taken forward for further expansion. This in turn led to new applications and features which were made available to the team for evaluation. Their evaluation often fed back information on how the new knowledge could be further expanded:

> *…when we investigated the golf course, we realized that there were different areas on the golf course, the green, and the fairway, the different sizes of grass… So I think everyone realized the potential - once you could manipulate grass then you can change a lot of the characteristics* (Project 3, Interview 2).

We identified nine (9) such instances of feedbacks (see Table 3 for other examples). This suggested that the evaluation and expansion stages involve repeated feedback loops. Here, we mostly found positive loops (see Table 3 for examples).

The knowledge was then taken forward to the refinement stage. The refinement stage invariably fed back information about the limitations of new knowledge to the expansion stage:

> *P does a set of experiments, comes back saying this is how it performs, and then if there is a….for example, the result shows you that you need to do it in a way that it is not beneficial to the customer, then we have to go back, trying to think how we can change it or adapt [the delivery design]* (Project 2, Interview 2).

We found thirty-two (32) such instances of feedbacks (see Table 3 for other examples). This suggested that the refinement and expansion stages invariably involve recurrent and iterative loops. Interestingly, and as shown in Table 3, we predominantly found that the loops represented a negative-positive combination: *…our first hypothesis turned out to be wrong [negative loop]…So that's when we started looking at DNA repair [positive loop], because we thought, well, we guessed…one thing that kinase might be doing might be…to be inhibiting DNA repair* (Project 7, Interview 2). Interestingly still, we also found the loops diverging (expanding or magnifying) because the new knowledge passed through several stages recursively. For example, following its expansion, it passed through the evaluation stage, before being refined, and the whole process repeated itself thereafter:

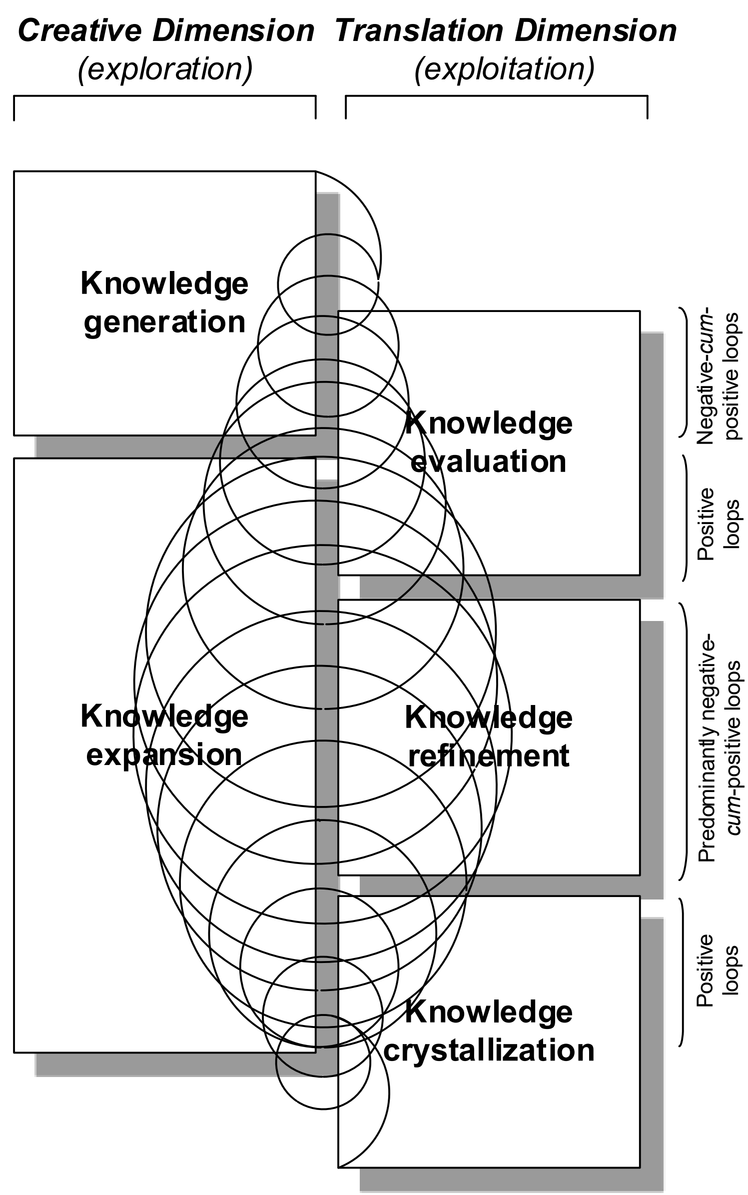
> *….the prototype would come back, we [would] test it against our own experimental criteria, and feedback any shortcomings. And we design that for the next prototype. It was an iterative process. Went through I think about seven or eight different prototypes…Prototypes, that's what they are, they are not products, they are prototypes. They get refined. So you go through the process of refining it by going through the cycle* (Project 2, Interview 2).

As a result of the above-mentioned iterative process, the knowledge started taking shape. It was then taken to the differentiation sub-stage. Differentiation also fed back information on how the new knowledge can be further expanded:

> *…the whole talk was where we did our separate bits, you know, we would present our few slides and then we'd get feedback from everyone. I mean you produce your three slides, your little bits, and then everyone would say, well, what you are saying is all well but say a little bit more* (Project 4, Interview 2).

We extracted eight (8) such incidences of feedbacks, all representing positive loops (see Table 3 for examples). This suggested that the differentiation and expansion stages often involve recursive loops. However, we also found the loops decreasing: *"...we were always talking. Always talking about the various bits of the bid. And discussing and throwing ideas in the pot. My recollection is everybody coming to a consensus about all of this"* (Project 1, Interview 3). We could only draw out two (2) instances post-differentiation to the expansion stage, which suggested a further reduction in the loops. We also found the loops converging, or shrinking, because with a fairly good idea of what they were developing, the new ideas which the team members came up with were readily incorporated into the new knowledge: *"...we really polished up on our graphics, and trying to think of good visual ways of getting the switching mechanism, and in the presentation, this could sort of click on and off, and the flowers appeared and disappeared"* (Project 3, Interview 4). This process continued until the knowledge was translated into a concrete and explicit form which – in our study – comprised a patent application, project document, funding bid, research paper, or concept presentation. Thus, we arrived at our dynamic knowledge-conceptualization model, as shown in Figure 1 below.

FIGURE 1
A Dynamic Model of Knowledge-conceptualization



Discussion and Conclusions

In this empirical paper, we model the front-end feedback loops as dynamic processes of OKC. We started with the innovations' front-end as our study's context, aiming to understand the dynamics of this highly uncertain phase. Doing that would have been difficult with the traditional, preference-driven approach to developing innovations, involving a stable sequence of steps and activities. OKC theory provided to us a situation-driven approach, involving the construction of new knowledge (e.g. innovations) as a contextual and emergent process (Nonaka, 1994; Nonaka and Takeuchi, 1995). This theory drove us to engage with and explore the front-end dynamics and draw out meaningful patterns. We focused on the feedback loops, whose dynamic patterns across the front-end we understand little. Existing models (e.g. Kline and Rosenberg, 1986; Rothwell, 1994) do not capture these patterns because they model loops around linear, or sequential, stages, even though stages overlap (Cooper, 2008; Schroeder et al., 1989). Akbar and Tzokas (2013) suggested how five front-end OKC stages (generation, evaluation, expansion, refinement and crystallization) overlap, but do not model the loops. Extending that framework, we model the loops based on the overlaps between/among stages. Using 10 qualitatively studied innovations we patterned the five stages and analyzed their associated feedbacks. We develop a unique model which distinctively illustrates the dynamic patterns of loops through which innovations are developed across the front-end.

Our model shows that the frequency, characteristics and types of loops are not uniform across the front-end. In line with the varying frequency of social interactions (Akbar and Tzokas, 2013), loops gradually increase from the generation-evaluation interface to maximise at the expansion-refinement interface, and decrease at the crystallization stage. In addition, loops diverge and magnify along the expansion-refinement interface, and converge thereafter. Moreover, loops are positive at the evaluation-expansion and crystallization-expansion interfaces, but are negative-*cum*-positive at the generation-evaluation and expansion-refinement interfaces. This abstraction sheds new light on our theoretical and managerial understanding of the front-end feedback loops. This we elaborate upon below to identify the boundaries of existing theory, increase precision in theories, and undertake theoretical refinements – all of which are essential for theoretical progress in organization and management research (Edwards, 2010).

Theoretical contributions

We firstly contribute to the literature on feedback loops by unearthing the evolving characteristics and types of loops not spelled out before. Loops are characteristically recursive and cyclical (Fischer, 2001; McCarthy et al., 2006). Our model shows that their characteristics vary along the process of developing innovations; less recursive and cyclically smaller at the beginning (generation-evaluation interface) and at the end (crystallization-expansion interface), but more recursive and cyclically larger in the middle, i.e. along the expansion-refinement interface, repeatedly passing through more than two stages. These nuanced patterns suggest that loops are far more complex and richer mechanisms than captured by the existing models (e.g. Kline and Rosenberg, 1986; Rothwell, 1994). Thus, we identify the boundaries of the existing models as well as extend the boundary of our current understanding to propose the following:

Proposition 1: The recursive and cyclical character of loops represents an inverted U-shape curve along the process of developing innovations.

Moreover, loops are typically categorized as either positive (reinforcing/stimulating) or negative (contradictory/limiting) (McCarthy et al., 2006; Sterman, 2001). Our model suggests that this distinct categorization gets rather blurred and may not completely apply to the process of developing innovations. While we found that the loops were distinctly positive at the evaluation-expansion and crystallization-expansion interfaces, they, wholly or predominantly, represented a negative-positive combination at the generation-evaluation and expansion-refinement interfaces. While the former two interfaces involved little or no conflict, the latter two interfaces involved (often volatile) conflict (e.g. creativity-*vs*- practicality or exploration-*vs*-exploitation), and this conflict was synthesized by the negative loops stimulating creativity (Leonard and Swap, 1999) and reflection to generate alternative, realistic ideas. Thus, we propose the following:

Proposition 2: Loops are positive at the non-conflicting interfaces and predominantly negative-*cum*-positive at the conflicting interfaces between stages.

Our second contribution is to the innovations literature and to the OKC literature more widely. In modelling the loops, we deviated from the linear approach, and instead used the dynamic approach to model the loops based on how stages overlap. By doing that, our model suggests theoretical refinements and precision in our understanding of the process of developing innovations. Scholars argue that the innovation process is not smooth or well-behaved

(Schroeder et al., 1989) and is somewhat disorderly (Kline and Rosenberg, 1986; Rothwell, 1994). Our model shows that the process is less smooth and well-behaved if – viewing our model from right to left – the focus is on the interactions *between* stages because the loops shift the process from one stage to another, giving the impression of a disorder. However, if – viewing our model from top to bottom – the focus is on the overall pattern of loops *across* stages the process may not be as disorderly as the existing understanding might suggest; loops reflect a systematic behaviour, in that they increase/diverge and then decrease/converge. Thus, we propose the following:

> *Proposition 3:* In the process of developing innovations there is, proverbially, an 'order in the disorder'.

Managerial Implications

Our model offers a clear and easy-to-comprehend knowledge-conceptualization journey, with increasing-decreasing, diverging-converging and frequent negative-*cum*-positive loops which resonate well with management thinking. These patterns suggest that managers need to encourage interactions at the evaluation, expansion and refinement stages (also during differentiation), and perhaps contain interactions at the integration sub-stage to, proverbially, 'get the job done'. Similarly, managers need to encourage conflict because it leads to reflection and creativity; yet, it also needs to be carefully monitored and controlled, especially at the expansion-refinement interface, to prevent it from becoming volatile and dysfunctional instead of positive. These insights are extremely important for managers because, while innovations promise highest returns, they do however incorporate substantial risks for firms venturing into such activities. It is, therefore, very important for innovation managers to appreciate the points where interactions need to be encouraged and converging signs applied so that the new knowledge can be crystallized and successfully applied to the innovation. For this, innovation managers need to have a clear understanding of how knowledge-conceptualization unfolds in practise and of the feedback loops which contribute to building knowledge across this phase. Our empirical model provides significant insights into these points. It offers clear guidance and opportunities for managers wishing to venture into the knowledge creation journey that successfully leads to innovations to reflect upon and question their practices.

Boundary conditions and future research agenda

Our study is limited to one-off innovation projects in the UK context. Future research can examine our model in different contexts (e.g. industry-specific or outside the UK). Other researchers can compare our model in initial and successive, or discontinuous and continuous innovations. Researchers can also examine the applicability of our model to other forms of formal and informal OKC processes, including, among others, developing routines, manuals, and business or marketing plans. Other researchers can extend our model to examine other types of loops, e.g. downstream (market-related) and upstream (technology-related) (Fischer, 2001). We collected data from participants, and the individual, team and organizational level insights emerged in the discussion. Future research can conduct a multi-level analysis, e.g. individual, team, SBU and/or organizational levels, to reflect upon different considerations underlying the feedback loops. Indeed, loops could be influenced by the trust and power-relations between actors, which were beyond the scope of our study, but which future researchers can further explore. Researchers can also extend our model post front-end to explore loops across the entire innovation process. Our projects occurred within organizations. Future researchers can examine our model's applicability to the context of collaborative communities of practice. Beyond the scope of our study was the organizational learning literature, though we did briefly touch upon Crossan et al's (1999) work. An interesting future research direction will be to integrate our model with the 4I framework (intuiting-interpreting-integrating-institutionalizing) of Crossan and his colleagues. Researchers could also link our model with the structuration theory, e.g. to examine the dualism of individual and organization in organizational learning (e.g. Berends et al., 2003). Also beyond our scope was the creativity literature. Future researchers can, therefore, examine our model, e.g. in the context of creative collectives (e.g. Hargadon and Bechky, 2006) or to understand the dynamic interplay between the idea generation and idea implementation stages (Amabile, 1988).

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