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UNDERSTANDING AND SUPPORTING DYNAMIC CAPABILITIES OF DESIGN TEAMS IN PRODUCTION OF TECHNOLOGY-INNOVATION

Ole Kjeldal Jensen

PhD Thesis

DTU Management Engineering
Department of Management Engineering

DONG energy

Understanding and supporting the creation of disruptive technology-innovation
PhD Thesis

Abstract

Rapid adaptation to a changing environment is essential for the survival of incumbent companies, but the capabilities required to lead the disruption of a technological trajectory are generally challenged by the process management activities that make the company operate efficiently within its current environment. This study explores the practices of engineering designers that are executing disruptive innovation projects for DONG Energy, a Danish energy utilities company. The aim of the study was to understand the role of the designer in disruptive innovation and to create a tool for supporting multidisciplinary design teams, while creating disruptive innovations. The results from this study are presented in five research Papers that address the following themes: 1) the willingness of engineers to follow formal procedures, 2) critical knowledge domains in front-end technology decisions, 3) knowledge management challenges when moving from front-end to product development, 4) the development of mechanisms for balancing exploration and exploitation activities in the processes of innovation, and 5) validation of mechanisms and boundary object creation by embedding it in the support tool Ensight for implementation and testing. The research design was based on the design research methodology (DRM) and case study research, with primary data collection conducted at DONG Energy through participating observations, large-scale workshops, interviews and experiments. The data amounted to a total of 486 hours of real-time observations, six interviews, and two workshops. To interpret the data, a theoretical framework was built on theories and concepts from engineering design processes, innovation processes, knowledge management, and intellectual capital.

The central findings from the study can be summarized as follows: 1) the effective implementation of new or radically changed methods and processes was found to be effectively supported by co-creating the method with the company; 2) the domains of knowledge that need to be covered by a disruptive design team include several fields that are

not traditionally associated with product development, such as market design; 3) the diversity of these domains was found to increase the barrier for effective transition from the front-end phase to the product development phase; 4) the transition gate was found to be a separate phase, with its own knowledge-management challenges; 5) a model of central mechanisms for supporting a messy innovation process with unpredictable flow was created by decoupling innovation support from the phases; and 6) embedding these mechanisms into a simulation game enhances the quality and quantity of disruptive concepts through the ability of the game to span and represent boundaries between knowledge domains. The contributions to research from this study include new perspectives on how capabilities for supporting disruptive innovation are created on the level of design teams. The study found that punctuated equilibrium exists on a micro-scale within an ambidextrous organization and that successful disruptive innovators are able to balance and synchronize exploration and exploitation without the support of process management. Furthermore, the study contributes to product development theory with an extended view of what defines the design dimensions of a product; factors such as market design were perceived to be essential design dimensions for the expected success of a product. This type of knowledge was successfully embedded into an object capable of spanning the boundaries of a multidisciplinary design team and of representing absent knowledge in the design team.

Dansk resumé

Hurtig tilpasning til et omskifteligt miljø er afgørende for overlevelsen af etablerede virksomheder, men opbyggelsen af de evner, der kræves for at lede et skift af teknologisk løbebane, bliver begrænset af de procesforbedringsaktiviteter, der gør at virksomheden fungerer effektivt i dens nuværende miljø. Denne afhandling udforsker praksis blandt de udviklere, der udfører potentielt revolutionerende innovationsprojekter [1]i det danske energiselskab DONG Energy. Formålet er at skabe en bedre forståelse af designteamets rolle i udviklingen af dynamiske kompetencer til at understøtte revolutionerende innovation, samt at skabe et designstøtteværktøjer specifikt rettet til forhold, hvor et etableret selskab sigter mod at lede revolutionerende forandring gennem teknologisk innovation. Resultaterne fra denne undersøgelse er præsenteret i fem videnskabelige artikler, der beskæftiger sig med følgende temaer: 1) Ingeniørers villighed til at følge formelle procedurer 2) identificering af kritiske vidensdomæner for tidlige teknologi beslutninger 3) vidensledelsesudfordringer i overgangen mellem tidlig innovation og produktudvikling 4) mekanismer for balancering af udforsknings- og udnyttelses aktiviteter i en rodet innovationsproces og 5) validering gennem indlejring af den udviklede teori i simuleringsspillet Ensight. Forskningsdesignet var baseret på designforskningsmetodik og casestudietilgangen, med den primære dataindsamling udført hos DONG Energy gennem deltagerobservationer, store workshops, interviews og eksperimenter. Datamængden beløb sig til i alt 486 timers real-time observationer, 26 interviews og to workshops. Til fortolkning af data, blev en ramme bygget på teorier og begreber fra: design- og produktudviklings processer, innovationsprocesser, vidensledelse og intellektuel kapital.

Det engelske "disruptive innovation" er oversat til "revolutionerende innovation"[1]

De centrale resultater fra undersøgelsen kan opsummeres som følger: 1) succesfuld Implementering af nye eller radikalt ændrede metoder og processer, støttes effektivt ved at samskabe metoden med virksomheden 2) vidensdomæner af kritisk betydning for et revolutionerende design-team omfatter flere felter der ikke traditionelt associeres med produktudvikling, såsom markedsdesign 3) mangfoldigheden af vidensdomæner øger barriererne for effektiv overgang mellem tidlig innovation og produktudvikling 4) overgangen mellem tidlig innovation og produktudvikling viste sig at være en separat fase, med særegne vidensledelsesudfordringer 5) en model af de centrale mekanismer for understøttelse af en rodet innovationsproces med uforudsigelige flows, blev skabt ved at afkoble innovationsstøtte fra innovationsfaser 6) Designeres brug af et simuleringsspil, med disse mekanismer indlejret, viste sig at øge kvaliteten og mængden af potentielt revolutionerende koncepter.

Afhandlingens forskningsbidrag omfatter en udvidet forståelse af, hvordan kompetencer der støtter design af revolutionerende innovationer bliver skabt på designteamniveau. Det blev konstateret, at punkterede ligevægtstilstande, der tidligere er observeret på makro-niveau, også forefindes på mikro niveau i en ambidekstral organisation og at succesfulde innovationsteams er i stand at balancere, men også synkronisere, udforsknings- og udnyttelses aktiviteter på tværs af virksomheden, uden støtte fra processtyring. Desuden har undersøgelsen bidraget til produktudviklingsteori med en udvidet opfattelse af, hvilke designdimensioner der definerer et produkt: faktorer, såsom markedsdesign blev identificeret som essentielle design dimensioner for det resulterende produkts succes. Denne type viden blev med succes indlejret i et objekt der spænder over vidensgrænserne i et tværfagligt design team samtidig med at det repræsenterer viden fraværende fra designteamet. Herved udvides forståelsen af hvordan vidensdomæner kan integreres under tværfagligt designarbejde.

Preface and acknowledgments

"At man, naar det i Sandhed skal lykkes en at føre et menneske hen til et bestemt Sted, først og fremmest maa passe paa at finde ham der, hvor han er og begynde der. Dette er Hemmeligheden i al Hjælpekunst. Enhver, der ikke kan det, han er selv i en Indbildning, naar han mener at kunne hjælpe en Anden. For i Sandhed at kunne hjælpe en Anden, maa jeg forstaae mere end han – men dog vel først og fremmest forstaae det, han forstaaer. Naar jeg ikke gjør det, saa hjælper min Mere-Forstaaen ham slet ikke. Vil jeg alligevel gjøre min Mere-Forstaaen gjældende, saa er det, fordi jeg er forfængelig eller stolt, saa jeg i Grunden istedetfor at gavne ham egentligen vil beundres af ham. Men al sand Hjælpen begynder med en Ydmygelse; Hjælperen maa først ydmyge sig under Den, han vil hjælpe, og herved forstaae, at det at hjælpe er ikke det at herske, men det at tjene, at det at hjælpe ikke er at være den Herskesygeste men den Taalmodigste, at det at hjælpe er Villighed til indtil videre at finde sig i at have Uret, og i ikke at forstaae hvad den Anden forstaaer." ***Søren Kierkegaard:***

"Brudstykker af en ligefrem Meddelelse"(*From a colleague in DONG Energy*)

Contents

1   Introduction

The context of contemporary companies is changing at an increasing rate and magnitude; thus, the periods of equilibrium for these companies have continuously become shorter, and the changes have become increasingly disruptive. Numerous factors have influenced this development, including increasing globalization, integration across multiple technological platforms in products and services, and institutional pressure for environmental sustainability, among others. The exponential increase in technology transfer and global corporate mergers underlines the trend from a globalization perspective: *Over this same time period [1980-2000)], international technology payments rose from $7.5 billion to over $60 billion. The number of cross-border mergers and acquisitions in 2000 was over four times the number in 1997 (9,200 transactions vs. 2,100)* (Javidan, Stahl, & Brodbeck, 2005)

The following statement on the integration of mobile devices into Google's technological platform reports a consolidation of products and features as a result of a disrupted market overflowing with opportunities: *Today, we live in a world of abundance... abundant information and abundant computing... ...While this abundance causes disruption, it also creates amazing opportunity...We have so many opportunities today, that unless we prioritize we spread ourselves too thin. Last month, we sunset another 19 products. We've now closed or have combined 60 products and features in the last year. And, we've put a ton of energy into ensuring that our remaining products work really well together.   Because as screens multiply, it's more important than ever that we converge our services* (Larry Page, CEO of Google Inc. 2012, 3rd quarter).

As companies must adapt to these changes, issues associated with acquiring new technological knowledge and making decisions for a radically uncertain future have drawn the attention of academics and managers alike. The idea for this project arose out of a dialogue between academia and industry concerning approaches for managing significant technological changes. Of more

specific concern was how approaches utilized in engineering knowledge management could be used to facilitate the transition from fossil fuels to sustainable fuels at an energy utilities company.

The general situation in the energy sector is that several indicators point to an upcoming technological transition, including fluctuating oil prices, resource scarcity, extreme weather phenomena, and the increased maturation of early sustainable energy technologies, such as large-scale wind power. In Denmark specifically, the energy system has undergone gradual changes over the last 20 years, resulting in wind turbines accounting for more than 30% of the installed electrical capacity in 2011. Therefore, the Danish energy system is reaching its technological limit for intermittent power, indicating that the strategy of sustaining the old system is reaching its end and that the continued integration of sustainable energy will require significant technological changes to the energy system and to how it is used. As a consequence, DONG Energy, a Danish energy utilities company, decided to establish an innovation center that was responsible for exploring feasible solutions to the challenges associated with significant technological change. Through further dialogue with the director of this upcoming innovation center, an industrial PhD project was initiated, with the mutual intent of developing a deeper understanding of design-work under technological change. This thesis describes the industrial PhD project performed with DONG Energy as the industrial partner and primary case company.

The Danish industrial PhD program differs from a traditional PhD program in that the student is formally employed by a company for the full duration of the PhD. As in the traditional PhD, the student has a university supervisor and is expected to divide time spent equally between the university and the company. The project was conducted over a four-year period, from 2009 through 2012, at the Technical University of Denmark (DTU), Management

Engineering, Design Engineering and Innovation (DEI) and was jointly funded by DONG Energy and the Danish Agency for Science, Technology, and Innovation.

1.1 Motivation

Innovation management within well established companies often employs generic normative models of structures and processes that are adapted to the specific conditions of the company. With these models as support, the companies aim to improve their competitive advantage through creating innovation. Innovation can be classified according to the outcome i.e. technologies, products, processes, business models, or any combination of these, but also according to the extent it departs from the paths of earlier innovations (See Table 1) (Berends, Vanhaverbeke, & Kirschbaum, 2007; Dodgson, Gann, & Salter, 2008; Markides, 2005). While these classifications are highly useful for analytical and predictive purposes, in a company innovation managers often find themselves managing multiple types of innovation simultaneously. In an effort to reduce uncertainty and to some extent equivocality, changes are made to the structures and processes governing innovation (Frishammar, Florén, & Wincent, 2011; Weick, 2012). However normative innovation theory dealing with the levels of innovation seen in Table 3 are of contradictory nature, making the adaptation to a context that combines incremental, radical, and attempts at disruptive innovation a challenging task.

Table 1: Hierarchy of technological innovation types

First level	Second level	Definition
Disruptive innovation		Innovation based on technologies that bring a very different value proposition to market. These typically start with performing worse than mainstream innovations and addressing fringe customers, but end out completely changing the rules of the game.
Sustaining innovation	Radical innovation	Innovation leading to great improvements in the performance of a product, in the eyes of the users.
	Incremental innovation	Innovation leading to minor improvements in the product, in the eyes of the users.

For scholars within the management field, the challenge of responding to or driving changes in a firms ecosystem through innovation has been receiving increased attention since (March, 1991) found that balancing exploration and exploitation became a major challenge for incumbent companies trying to adapt to a changing environment or to proactively change it. This challenge is further supported by (O Reilly & Tushman, 2004) who state that the appropriate integration of exploration and exploitation presents a consistent dilemma for innovating organizations. An empirical study of companies in the Standard & Poor 500 group determined that the average life expectancy of a company in 1935 was 90 years; in 1975, it was 30 years; and in 2005, it was estimated to be 15 years (Foster & Kaplan, 2001). (March, 1991) describes long-term survival as balancing between the two extremes of adapting to the context and appropriating earnings:

Adaptive systems that engage in exploration to the exclusion of exploitation are likely to find that they suffer the costs of experimentation without gaining many of its benefits. They exhibit too many undeveloped new ideas and too little distinctive competence. Conversely, systems that engage in exploitation to the exclusion of exploration are likely to find themselves trapped in suboptimal stable equilibria (March, 1991).

Much research has been done on balancing exploration and exploitation by management scholars, especially on the level of strategy and structures, where the two concepts of punctuated equilibrium (Gersick, 1991) and the ambidextrous organization (Tushman, Anderson, & O'Reilly, 1997) are found. The punctuated equilibrium view is inspired by evolutionary theory; in this view, a company is perceived as living in a state of equilibrium punctuated by disruptive periods of exploration. These periods can either be proactively initiated by the company or can occur as a reactive response to a changing environment. The ambidextrous organization theory builds upon the proactive view, proposing the creation of a structure in which both exploration and exploitation can occur simultaneously by embedding

these two conflicting approaches in separate entities within the company. The focus on high-level management is maintained in the dynamic capabilities view, in which the abilities of a company to integrate, reconfigure, create, and disseminate resources are perceived as crucial to a firms adaptation to its environment (Eisenhardt & Martin, 2000; Teece, 2007).

In recent decades, much attention has been focused on static process management activities, such as ISO 9000 and lean and business process reengineering, among both industrial managers and management researchers (Cooper, 1988; Cooper & Edgett, 2008; Grönlund, Sjödin, & Frishammar, 2010; Rogers, 2003)

The engineering design field has been similarly occupied with improving the quality of designs and the management of design activities through process management (see, e.g (Blessing & Chakrabarti, 2009; Hales, 1987; Pahl, Beitz, Schulz, & Jarecki, 2007; Ullman, 1992). One difference between the management perspective and that of engineering design is that engineering design tends to view the process from the designer creating the innovation, whereas management scholars often remain on the plane of theory creation. A synthesis of these two views on the innovation process from a dynamic perspective could lead to novel theoretical insights into the evolution and use of dynamic capabilities while at the same time lead to novel ways of supporting the designers.

Thus far, scant attention has been paid to how the design-team level supports innovation through contributing to the dynamic capabilities within a firm, as it lies in the area between these two traditional fields of research. Furthermore, the extensive attention to the static process management inherent in support created in both fields was observed by (Benner & Tushman, 2003) to be largely counter-productive when attempting to engage in exploratory innovation activities as the processes that make an incumbent company perform well in its current context become the primary barriers to adaptation.

A more productive approach to balancing exploration and exploitation appears to be knowledge management on the team level, where knowledge diversity and depth in teams has been shown to enable an ambidextrous innovation approach (Taylor & Greve, 2006). This view is further supported by empirical research showing knowledge management as an essential infrastructure behind a firm's dynamic capabilities. The knowledge management infrastructure supports dynamic capabilities through enabling processes of knowledge evolution, which ultimately results in improved operational capabilities (Cepeda & Vera, 2007; Pavlou & El Sawy, 2010; Zollo & Winter, 2002). A similar argument is made by Kogut & Zander (1992) who describes the existence of "combinative capabilities" as a prerequisite for integrating existing resources into new applications.

With this background in a dynamic knowledge view on innovation processes, a gap in the literature was identified regarding the understanding of how a design team working on multiple levels of innovation contributes to the creation of dynamic capabilities and how the underlying knowledge management infrastructure can be improved to support this process.

The importance of addressing this gap is supported by (Gupta, Smith, & Shalley, 2006) who found that research originating on the individual and team level of organizational capabilities for exploration and exploitation is needed to further advance research in operational balancing of exploration and exploitation. Also, Peteraf, Di Stefano, & Verona (2013) shows that more inductive empirical research in the processes behind the evolution and use of dynamic capabilities are needed, as the research field is currently divided into camps defined by theoretical stances. Hence, further inductive empirical research could assist in bringing these camps together.

This study is addressing the gap by answering the following research questions:

How may support for design teams' contribution to dynamic capabilities be added to the knowledge management infrastructure that supports the designers in creating innovation on all levels of innovation height?

From this question, a set of sub-questions (SQs) was created, each of which was treated separately in the five research Papers included in the thesis. The questions were:

SQ 1. Are established design procedures used in the way they are intended? How can design procedures be turned into a widely accepted supportive tool for transferring critical knowledge between design engineers and service engineers managing paradigmatic knowledge that is *new to the company*?

SQ 2. How are decisions regarding technologies informed in the early phases of innovation when managing paradigmatic knowledge that is *new to the company*?

SQ 3. How do product development managers who are responsible for innovation in a large company perceive the knowledge management challenges that they face throughout the innovation process?

SQ 4. How are dynamic capabilities for innovation evolving at the deisgn-team level, and through which mechanisms do these capabilities support the innovation process?

SQ 5. How may spanning of boundaries that are caused by knowledge asymmetries in multidisciplinary design teams be supported during innovation projects?

1.2 Outline of the thesis

This thesis is formulated as a collection of Papers, and as such, it is divided in three parts:

Part 1) contains this introduction in chapter one, a literature review in chapter two, a description of the overall research design and methodology in chapter three, and an overview of the contributions in chapter four; it concludes with a discussion and conclusion drawn from all of the Papers in chapter five.

Part 2) contains the five research Papers formulated during the project are presented in the order in which they fulfil the logical flow of the Design Research Methodology (DRM) (see Figure 1). This model is explained in detail in the methodology chapter; therefore, it suffices to say at present that the model moves through four phases: the goals for the research are determined, the phenomenon at hand is rigorously described, a prescription for addressing the issues discovered is generated, and finally, the prescription is validated. Papers no. 1 and 2 are conference Papers and Papers no. 3 through 5 are journal submissions. As Paper no. 3 is an extension to a published conference Paper from ICED 11, the original conference Paper is included in the appendix for reference.

Part 3) contains the appendices, which, in addition to the ICED 11 Paper, include the code definitions, the semi-structured interview guide, a description of the simulation game Ensight, and a chronologically structured data trail.

Research Questions

SQ 1: Are established design procedures used in the way they are intended? How can design procedures be turned into a widely accepted supportive tool for transferring critical knowledge between design engineers and service engineers managing paradigmatic knowledge that is *new to the company*?

SQ 2: How are decisions regarding technologies informed in the early phases of innovation when managing paradigmatic knowledge that is *new to the company*?

SQ 3: How do product development managers who are responsible for disruptive innovation in a large company perceive the knowledge management challenges that they face throughout the innovation process?

SQ 4: How are capabilities for disruptive innovation created at the team level, and through which mechanisms do these teams support the innovation process?

SQ 5: How may spanning of boundaries that are caused by knowledge asymmetries in multidisciplinary design teams be supported during disruptive innovation projects?
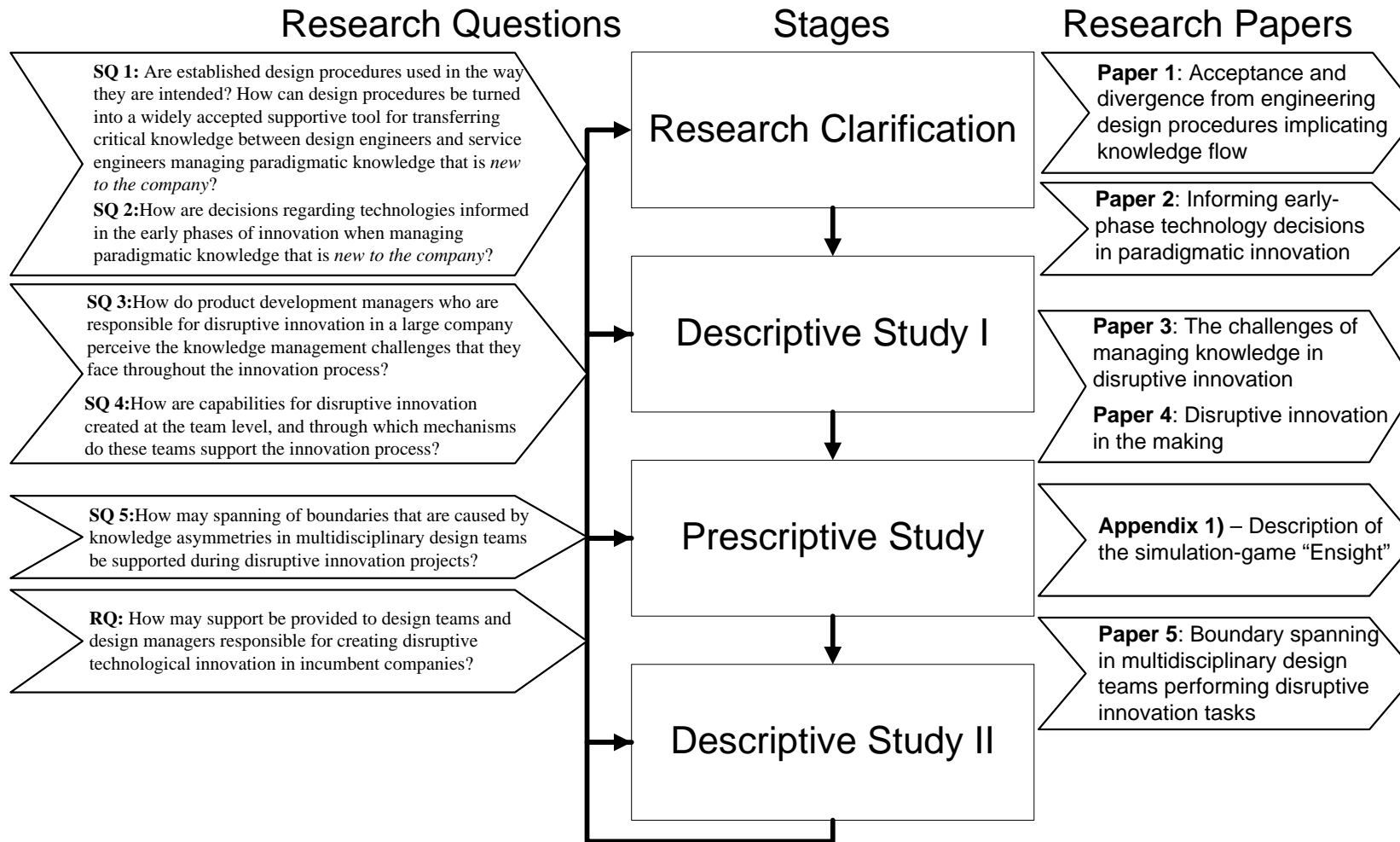
RQ: How may support be provided to design teams and design managers responsible for creating disruptive technological innovation in incumbent companies?

Stages

Research Clarification

Descriptive Study I

Prescriptive Study

Descriptive Study II

Research Papers

Paper 1: Acceptance and divergence from engineering design procedures implicating knowledge flow

Paper 2: Informing early-phase technology decisions in paradigmatic innovation

Paper 3: The challenges of managing knowledge in disruptive innovation

Paper 4: Disruptive innovation in the making

Appendix 1) – Description of the simulation-game "Ensight"

Paper 5: Boundary spanning in multidisciplinary design teams performing disruptive innovation tasks

Figure 1: Outline of the thesis based on the Design Research Methodology framework

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1.3   Phenomenological connection between thesis parts

This study moves between two levels of analysis within a knowledge based theoretical framework. These levels are naturally reflected in the scientific papers: Paper 1 through 3 addresses the innovation processes on a department level, with specific attention to understanding the differences between formal and informal processes (Paper 1), criteria for go/no-go decisions in the transition between front-end and the formal product development process (paper 2), and challenges in the knowledge management infrastructure that lies behind the dynamic capabilities (paper 3). Paper 4 takes a multilevel perspective, where department and teams are analysed in terms of evolution and use of dynamic capabilities. Paper 5 finishes off by moving completely down to the within-team level, where the prescription is a dynamic addition to the current knowledge management infrastructure, tested with the design professionals across the organisation.
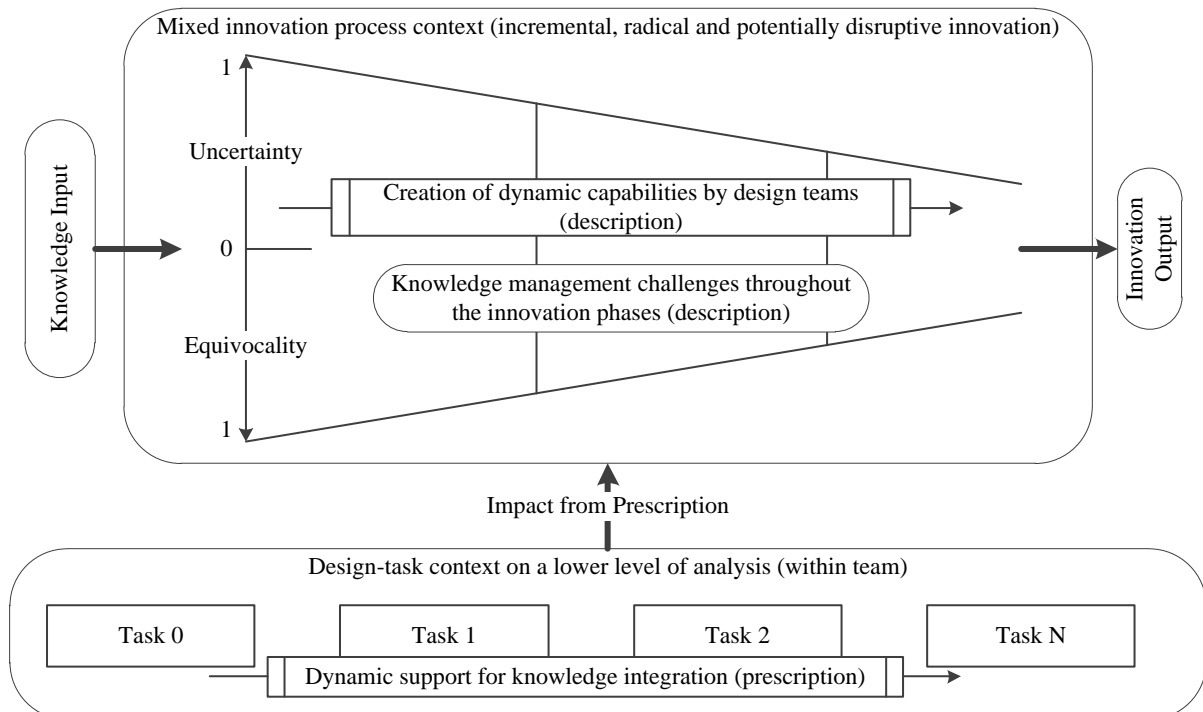
Figure 2: Connection between the two central levels of analysis: A deep understanding of the design-team in the context of innovation informed the creation of a prescription that works on a lower level: within the design team

2   Background and positioning of the study

In this chapter, the theoretical background for the project is presented, with the purpose of positioning the study in regards to existing literature on the subject, and defining the central theoretical concepts. The chapter discus the following theoretical areas: innovation as a research field; design, innovation and product development processes; Knowledge, knowledge management and dynamic capabilities; and the synergies between design and management research.

2.1   Innovation as a research field

Innovation is investigated in several different fields of science, each of which has its own concepts and foci of attention. The literature on innovation research in the areas of engineering design, economy, organizational sociology and technology management was reviewed to gain an overview of innovation research projects in different fields and their foci. The distinctive dimensions of innovation research were found to be the type of innovation, stage of process, and level of study (see Table 3). Economists tend to focus on the effects of industrial-level innovation at the macro-economic level of performance, such as employment and national productivity. Technologists are split between training their focus on the effects of new technological innovations on organizations and how technological innovations are created and managed within organizational sub-units. Sociologists split their focus between identifying factors on the organizational level that can explain the variance in innovation adoption and the process of innovation at the firm level, including how innovation is affected by social systems (Gopalakrishnan & Damanpour, 1997) . This study is primarily placed in the organizational technologist field and secondarily in that of the process sociologist as the research question draws the attention to how the performance of a technologically focused and highly diverse design-team can be improved.

There appears to be a consensus across the fields of innovation research that radical and incremental innovations should be distinguished. However, the labelling tends to vary somewhat, with radical, discontinuous, breakthrough, and disruptive innovation being synonymous on one side and incremental, continuous, and sustaining innovation being synonymous on the other side (McLaughlin, Bessant, & Smart, 2008). In an operational sense, the degree of change in the activities and practices of a firm or industry caused by an innovation is commonly used by researchers to determine whether an innovation is on one side of the continuum or the other (Ettlie, Bridges, & O'keefe, 1984; McLaughlin et al., 2008). Traditionally, change is assessed along two dimensions, market and technology; a high degree of change in either or both classifies the change as radical. While (McLaughlin, 2008) finds that the underlying themes in the different labels for radical innovation appear to be consistent and therefore synonymous, (C. M. Christensen & Raynor, 2003) argue that the concept of disruptive innovation differs in that it changes the "rules of the game" across the entire industry instead of affecting just one company. Thereby, radical innovation becomes a subset within sustaining innovation. (C. M. Christensen & Raynor, 2003) argue further that it matters little whether the innovation is of a technological nature or of non-technological, such as a business model; the effect on the organization is similar, and the important distinction lies between sustaining innovation and disruptive innovation. The general use of the disruptive innovation concept by Christensen and others has been criticized by (Danneels, 2004) and (Markides, 2005), among others, who argued that technology, product, and business model innovation must be separated. If only considered at the organizational level, the three types of innovations may have identical disruptive effects but with different managerial implications. Separating these three types of innovations allows researchers to progress further into micro-levels of disruptive innovation by providing a meaningful framework from which meaningful managerial responses to disruption can be prescribed

(Markides, 2005). In Table 2, a synthesis of the different views on innovation classification is provided, where radical and incremental innovation is presented as a subset of sustaining innovation in line with C. M. Christensen & Raynor (2003) and where the definitions of innovations within each class are kept tightly to technological and product innovation in line with Danneels (2004) and Markides (2005). Similar charts could be created with a focus on e.g. business model innovation. However, as a close connection between the engineering design view and the innovation process management view is desired, the business model perspective has been left out from this model.

Table 2: Hierarchy of technological innovation types used in this study.

First level	Second level	Definition
Disruptive innovation		Innovation based on technologies that bring a very different value proposition to market. These typically start with performing worse than mainstream innovations and addressing fringe customers, but end out completely changing the rules of the game.
Sustaining innovation	Radical innovation	Innovation leading to great improvements in the performance of a product, in the eyes of the users.
	Incremental innovation	Innovation leading to minor improvements in the product, in the eyes of the users.

While these classifications are highly useful for analytical and predictive purposes, the situation in a company is often that innovation managers find themselves managing multiple types of innovation simultaneously (Davenport, Leibold, & Voelpel, 2007). Thereby, the context observed in empirical studies involving multiple innovation projects will often be a combination of these classes.

Table 3: Differences in conceptualization among economists, technologists and sociologists (Gopalakrishnan & Damanpour, 1997)

Theoretical field	Type of Innovation	Stage of process	Level of study	Exemplary research questions	Exemplary references
Economists	Product and process Only technical Only radical	Generation Idea generation Project definition	Industry	- Who innovates more – the large firm or the small firm? - What is the nature of the link between industry R&D and economic progress?	(Kamien & Schwartz, 1975; Winter, 1984)
Technologists Contextual technologists	Product and process Only technical Radical and Incremental	Generation Commercialization and marketing Diffusion	Innovation (in the industrial context)	- What is the nature and dynamics of technological change at the industry level? - What is the impact of technological breakthroughs on the environmental condition of the firm?	(Tushman & Anderson, 1986; Utterback & Abernathy, 1975)
Organizational technologists	Product and process Only technical Radical and Incremental	Generation Idea generation Problem solving adoption Adoption Initiation	Organizational Sub-system	- How can diversity within R&D groups be managed effectively to improve the productivity of the R&D teams? - How do process characteristics (e.g. communication, decision making facilitate the technical performance of R&D laboratories?	(Leonard-Barton & Sinha, 1993; Tushman, 1981)
Sociologists Variance sociologists	Product and process Technical and administrative Radical and Incremental	Adoption Initiation Implementation	Organization	- What characteristics distinguish early adopters of innovation from laggards? - Which class of variables (e.g. structure, process, context) are most important in explaining variability in adoption behavior?	(Dewar & Dutton, 1986; Ettlie et al., 1984)
Process sociologists	Product and process Technical and administrative Radical and Incremental	Adoption Initiation Implementation	Innovation (at the organizational level)	- How do innovations actually develop over time from concept to implemented reality? - How can an organization develop and maintain a culture of innovation and entrepreneurship?	(Rogers, 2003; van, 2000)

2.2 Design, innovation and product development processes

The following historical review of processes models plays an important role in the conceptualisation and understanding of the empirical innovation process that provided the context in which the studies of design teams were carried out.

Throughout the 1950s and 1960s, engineering designers were engaged in constructing increasingly complex technologies for programs such as the Sputnik and Apollo space programs, for supersonic flight, and for the first nuclear power plants (Obninsk in the USSR and Calder Hall in the UK). These technologies had strong roots in the established natural sciences and the large national research projects during the World War II, such as the Manhattan project (Beckman & Barry, 2007). The collaboration between engineering designers and scientists made the engineering designers aware that their processes for embedding new technologies into artifacts were less rigorous and explicit than those of the scientists (Simon, 1988). Furthermore, the increased collaboration with scientists and engineers from other disciplines necessitated the explication of the engineering design methodology to communicate it to their collaborators. The methodological descriptions, in turn, enabled a higher degree of reflection on the trial-and-error methods of the past. As a consequence, engineering designers became aware that they required more predictive and evaluative methods for determining the suitability of their designs (Gregory, 1966). The scientifically inspired search for a single rationalized method of design – akin to the scientific method – dominated the early years (Cross, 2001). Early in these endeavors, it became clear that scientists and designers had different ways of solving problems; designers solve problems through synthesis, i.e., by proposing a series of solutions and then eliminating the worst candidates until an acceptable solution is reached. Conversely, scientists solve problems through analysis, i.e., by systematically exploring a problem with the goal of discovering the rules that allow them to create or discover solutions (Lawson, 1979). This

realization led to the formulation of the co-evolution of problem and solution, i.e., that

solution conjectures should be used as a means for understanding the problem (Cross, 2007).

(Buchanan, 1992), among others, has shown this strategy to be a particularly efficient way of

addressing "wicked" problems, i.e., problems in which all of the required information can

never be available to the problem solver. The concept of wicked problems applies to

designing highly novel innovations (e.g. radical or disruptive) in which the market and/or

technology can never be completely analysed beforehand as it is likely that it will

significantly change the context in which it will be embedded. The shift from the scientific

method to the synthesis method is described by (Beckman & Barry, 2007) as two generations

of design methods (see Table 4)

Table 4 Generations of design methodologies (Beckman & Barry, 2007)

Generation of design methods	Key features
First generation	Decomposition of problems, cybernetics thinking, expertise in sub-disciplines, mechanistic view on the design process
Second generation	Design as a social process, problem formulation process, establishing collectively acceptable starting points.

Inspired by the same booming post World War II technological growth that inspired the

engineering designers, economists started to study the relationships between investments in

science and technology and economic growth. However, these studies did not explain

sufficiently why certain companies were outperforming others, and as a consequence, the

economists turned their analyses to the inner workings of the company (Asimakou, 2009).

Much of the new management research was inspired by Schumpeter's (1942) work on

innovation and entrepreneurship, i.e., the idea that companies will revolutionize the economic

structure through the process of creative destruction (Schumpeter, 1942). Thus, the

characteristics of the innovation process in a company became the early center of attention

for management research (Berchicci & Tucci, 2006), (Asimakou, 2009).

Over the next 25 years, the view on innovation was to change significantly, as described by (Rothwell, 1992) in his overview of the evolution of innovation management models since the mid-1960s. An adapted overview of the five generations identified by Rothwell (1992) has been formulated by combining the work of (Tidd & Bessant, 2009) with that of (Dodgson et al., 2008) (see Table 5)

Table 5 Rothwell's five generations of innovation models, adapted from (Tidd & Bessant, 2009) and (Dodgson et al., 2008)

Generation	Key features (Tidd & Bessant, 2009)	Process representation (Dodgson et al., 2008)
First	Simple linear technology-push model	
Second	Simple linear market-pull model	
Third	Coupling model, recognising interaction between different elements and feedback loops between them	
Fourth	Parallel model, integration within the company, upstream with key suppliers and downstream with demanding and active customers, emphasis on linkages and alliances	
Fifth	Systems integration and extensive networking, flexible and customised response, continuous innovation	

In the first models, the process view was simple and linear, while the latest models are highly complex, involving open networks and ecosystems. In particular, in the fifth generation of innovation models, the perspective of companies as actors in a large ecosystem of networks became prevalent, even though (Rothwell, 1992)'s work preceded the widespread use of the internet. The view of ecosystems of collaborative networks has been adopted in recent research by (Chesbrough, 2004) and (Scharmer, 2009), among others. This type of evolution from a linear, planning-based, cybernetics view of systems into the view of complex and adaptive systems occurred within both engineering design methods and innovation management models. This parallel development of the traditions and the common point of origin in complex technology projects suggest that there is much to be learned from integrating knowledge of these two distinct traditions. From these two fields, iterative prescriptive models for supporting designers and managers have been surfacing in recent years, such as design thinking (Brown, 2008) and Theory U (Scharmer, 2009) in which the cybernetics view is replaced by the complex adaptive systems view, as described by (Van de Ven, Polley, Garud, & Venkataraman, 1999).

Despite recognizing that processes are complex, a consensus remains that simple flow-illustrations are useful support for practice as conceptual models of a complex reality (e.g., (Tidd & Bessant, 2009), (Dodgson et al., 2008), (Davenport et al., 2007). Therefore, a review of selected existing innovation models was conducted to identify their core support functions. These functions have been detached from the process management view in recognition of the inherently messy and constantly adapting innovation process and of the need for pragmatic support for innovation teams (see Table 6).

Table 6
Functional view on innovation support – conceptual model for analysis

Innovation model	Knowledge	Decision	Foresight	Reference
Stage gate	Market and technology analysis, idea generation	Initial screening, gates	Ideas, roadmaps, forecasts, preliminary assessments	(Cooper & Edgett, 2008)
Open Stage gate	External network, design, idea generation	Gates, boundaries, validate, design	Define	(Grönlund et al., 2010)
Diffusion of innovation	Knowledge, confirmation	Persuasion, implementation decision	Persuasion	(Rogers, 2003)
"Minnesota studies"	Development	Implementation Initiation	Initiation	(Van de Ven et al., 1999)
Front end of innovation	idea genesis, opportunity analysis, concept and technology development	Idea selection, engine, commercialization	Opportunity identification,	(Koen et al., 2001)
Theory U	Downloading, seeing, sensing	Prototyping, performing	Presencing, crystallizing	(Scharmer, 2009)

The six theories selected represent both linear and non-linear models, and the elements of each model have been categorized according to their primary function. Consequently, certain elements belong to more than one category as they fulfil multiple functions. The result of this categorization is to elicit the three generic support functions of *knowledge, decision and foresight*. Therefore, it is not the exact positioning of the elements that is the result of this analysis but the three support categories that has been synthesised. The first category is support for knowledge-related activities, such as creating, utilizing and sharing knowledge. The second category is support for decision-related activities, such as methods for selecting the best alternatives and single item selection. The last category covers foresight-related activities, such as idea generation, future scenarios, and persuading stakeholders to recognize assumption goals and strategies.

2.3 Knowledge, knowledge management & dynamic capabilities

The knowledge based view (KBV) of the firm has been adopted as a central framework for understanding knowledge and knowledge management throughout the innovation process (Eisenhardt & Martin, 2000; Eisenhardt & Santos, 2002; Grant, 1996). Thereby, it has been an essential tool for what is the highest level of analysis within this project.

KBV is often considered an extension to the resource based view (RBV) of the firm as it maintains the view of a firm as a heterogeneous entity, where the source of sustainable competiveness is the internal resources in the firm (Grant, 1996). However, KBV distinguishes itself from RBV by focusing on knowledge as the central resource of strategic differentiation rather than knowledge as one resource among many and proposes that the firms exist to create, transfer and transform knowledge into competitive advantage (Kogut & Zander, 1992). Knowledge is thought of as embedded into and carried through culture, processes and routines, identity, documents, IT systems, and people. Four major streams of empirical studies within KBV are: sourcing, internal transfer, external transfer and integration (Eisenhardt & Santos, 2002). In order to conceptualize the innovation process, especially the internal transfer and integration streams proved to be central.

Grant (Grant, 1996) presents a view on the company as an integrator of knowledge, based on the argument that efficient production (of e.g. innovations) requires integration of many peoples knowledge through establishing a mode of interaction where knowledge is integrated with minimal requirements for costly knowledge transfer. In order to facilitate this, four types of coordination mechanisms are proposed: rules and directives, sequencing, routines, and group problem solving and decision making. The latter of the coordination mechanisms is the only one that directly addresses equivocality and by far the most expensive; hence it is often reserved to unusual and complex cases.

These four mechanisms are all reliant on some degree of common knowledge for their operation, as the common knowledge allows individuals to integrate the parts of their respective knowledge domain that is not common. Examples of common knowledge that fulfill different roles during knowledge integration include: language, other forms of symbolic communication, commonality of specialized knowledge, shared meaning, and recognition of individual knowledge domains. In a team, this common knowledge is gradually build up through a circular process where the team performs a task, an outcome is achieved, the team explores causal relations between actions and outcomes, and common knowledge is gained (Dixon, 2000). The more iterations that a team undertake together, the more common knowledge they gain and the more efficient they get at integrating their respective uncommon knowledge (Eisenhardt & Santos, 2002; Grant, 1996). Exercises where teams solve concrete tasks related to their knowledge domains has been shown to accelerate the creating of common knowledge (Bechky, 1999). Even though the coordination mechanisms are essential to create efficient integration of knowledge, it has been shown that complicated rules, routines and work descriptions can increase the barriers to knowledge integration (Dougherty, 1992). However, other studies (e.g. (Hargadon & Sutton, 1997; Okhuysen & Eisenhardt, 2002)) point out that routines and rules can be used to improve knowledge integration and hence these have impact on knowledge integration although it is unclear how. The effective rules and routines seems to be the ones that allows freedom for interpretation and creative implementation, whereas the inefficient ones are the heavily rigid procedures, which quickly become obsolete and starts to hamper knowledge integration (Eisenhardt & Santos, 2002).

The central concepts from research into internal knowledge transfer are: the characteristics of knowledge, the sender, the recipient and their mutual relationship (Eisenhardt & Santos, 2002). This is at the same time one of the central areas of knowledge management (KM): to

facilitate an efficient transfer of knowledge between sender(s) and receiver(s) which could e.g. be the engineering design teams and the innovation managers or between individuals within this team.

The term "knowledge management" is broadly used by researchers from several fields and covers any systematic attempt of an organization to influence the flows of data, information, and knowledge (see Table 7). Extensive research in several fields under this term has led to significant progress in how knowledge is managed at all levels of the organization; this research has also led to multiple definitions of these three terms, which makes it imperative to re-define these key terms and concepts in each study (Jakubik, 2007). The definitions of knowledge, information and data used in this study are as follows: The form of the stimuli that are sent back and forth between actors in a network, whether they are human or non-human, can be described by the following terms: data, information, and knowledge (Jensen & Ahmed, 2010), (Ahmed, Blessing, & Wallace, 1999), (Dixon, 2000), (Davenport & Prusak, 1998a). Various definitions for these terms are based mainly upon an epistemological view and the context in which the terms are used (K. S. Christensen & Bukh, 2009). As this study takes a process perspective on the creation of innovation, the active process perspective described by (Blackler, 1995) where knowledge is considered as active (knowing) is used in combination with the concrete definition proposed by (Wallace, Ahmed, & Bracewell, 2005). Thus, data are considered a set of discrete, objective facts about events; they are raw and unstructured in nature, information is view is what is stored and transferred outside the human mind is in some kind of structure, and knowledge only exists when information is interpreted.

Table 7 concepts and theories within knowledge management research (Baskerville & Dulipovici, 2006)

Applied purpose in knowledge management	Theoretical foundation	Key theories drawn from this foundation	Developed key knowledge management theories	Exemplary references
Rationale	Information economics	Intellectual capital, intellectual property	Knowledge economy, knowledge networks and clusters, knowledge assets, knowledge spillovers, continuity management	(Foray, 2004; Teece, 2000)
	Strategic management	Core competencies, dynamic capabilities	Dumbsizing, knowledge alliances, knowledge strategy, knowledge marketplace, knowledge capability	(Conner & Prahalad, 1996; Inkpen & Dinur, 1998)
Process definition	Organizational culture	Cultural values, power, control and trust	Knowledge culture	(David, Long, & Fahey, 2000; Graham & Pizzo, 1996)
	Organizational structure	Goal-seeking organizations	Knowledge organizations	(Dyer & Nobeoka, 2002; Starbuck, 1992)
	Organizational behavior	Organizational creativity, innovation, organizational learning, organizational memory	Knowledge creation, knowledge codification, knowledge transfer/reuse	(Hansen, Nohria, & Tierney, 1999; Markus, 2001; Nonaka & Takeuchi, 1995)
	Artificial intelligence	Knowledge based systems, data mining	Knowledge infrastructure,. Knowledge architecture, knowledge discovery	(Davenport & Prusak, 1998b; Shaw, Subramaniam, Tan, & Welge, 2001)
Evaluation	Quality management	Risk management, benchmarking	Knowledge equity, qualitative frameworks	(Glazer, 1998; Jordan & Jones, 1997)
	Organizational performance measurement	Financial performance measures	Performance indices	(Ahn & Changb, 2004; Chang Lee, Lee, & Kang, 2005)

In this study, knowledge integration and knowledge transfer/reuse theories are primarily drawn upon as the central purpose has been to define the innovation process. A critical issue within the organizational behavioural view is the concept of tacit versus explicit knowledge as the focus is on integrating knowledge and transferring it across domains and individuals. A classification of knowledge that builds on the definition of tacit and explicit knowledge proposed by (Polanyi, 1966) is found in (Wallace et al., 2005). This classification describes tacit knowledge as knowledge that is impossible to explicate and of which the user is not readily aware. Implicit knowledge refers to a middle point in the continuum between tacit and explicit knowledge and is defined as tacit knowledge that is possible to explicate through an eliciting process. Finally, explicit knowledge is defined as knowledge that the holder is easily capable of explicating syntactically. From the perspective of innovation processes, an organization's ability to combine and integrate tacit, implicit and explicit knowledge from different domains, such as technology and market analysis, is essential to the production of new knowledge and thus is essential to the novelty of innovation (Nonaka, Toyama, & Konno, 2000).

According to (Hansen et al., 1999), there are two organizational strategies for managing knowledge transfer across domains, distinguished by whether the purpose is to capture knowledge in encoded form or to facilitate people meeting for the purpose of sharing knowledge. The first strategy is *codification*, i.e. retrieving knowledge from persons and repackaging it, for example, into a large database, thus achieving economies of scale by reusing the knowledge object (Foray, 2004). The second strategy is *personalization*, i.e. transferring knowledge from person to person via direct contact, such as by deliberately matching people and creating transparency in the organization. Knowledge asymmetries between individuals and groups, such as communities of practice (Wenger, 1999), create and maintain the distinct groups within organizations and within multidisciplinary teams. The

barriers for knowledge transfer between these groups are substantial, as is the ability of these groups to naturally blend. For an efficient collaboration, knowledge transfer alone is not efficient as it would mean one specialist learning the entire field of the other specialist to create a product of the two knowledge domains. In this case, it is more efficient to transfer just enough knowledge to understand the other specialist's field and then create the product through integrative collaboration between the specialists. This process has been found to require substantial support, either in human form through boundary spanning or through the use of artifacts, such as boundary objects.

Knowledge brokering is a concept widely used by Wenger (Wenger, 1999) in the communities of practice theory. Brokering is boundary spanning performed by humans with dual membership in communities in which the community is the embodiment of a knowledge domain. The broker performs boundary leadership, which is the function of keeping two communities connected. Through brokering, elements of one domain (e.g., know-how) are transferred to the other. When members of communities enjoy dual membership, it does not automatically lead to brokering because something must be transferred if the activity is to be designated as brokering – potential brokering is often hindered by factors such as social status and seniority. The broker will often bring crucial knowledge to the different networks to which he belongs; however, brokers are often not fully accepted by the communities they connect. Wenger states that the main challenge of brokering is the challenge of avoiding the two opposing tendencies of being pulled into full membership and being rejected as an intruder.

The term boundary object is used widely by sociologists in knowledge management and was originally coined by Star (Carlile, 2002; Wenger, 1999). The boundary object is an entity capable of facilitating the transfer of knowledge across a sociologically defined boundary (e.g., general assembly drawings facilitating knowledge transfer between engineers and the

workshop). This definition indicates that a boundary object is strongly related to the concept of translation, which is found in actor network theory (Carlile, 2002), by being capable of performing a translation process. However, it is also related to the definition of brokering from communities of practice because it represents the objectification of the brokering activity, which is being able to move elements of one practice to another (Wenger, 1999). When used to facilitate knowledge transfer across knowledge domains in an organization, e.g., between product development and production departments, (Carlile, 2002) emphasizes the importance of understanding the true ends of each of these departments. The true end is what the department aims their actions at; for example, in a sales department, the true end would be closing a deal, and in a design department, the true end would be passing design review. The reason for looking into these ends is that good boundary objects are recognized by the users as moving them closer to their perceived end, hence a 'good' boundary object is not necessarily the same thing from one department to another department.

The entire knowledge management infrastructure of a firm, on all its different levels, has been found in empirical research to be the most essential support for the evolution of dynamic capabilities (Cepeda & Vera, 2007; Eisenhardt & Martin, 2000; Zollo & Winter, 2002). Dynamic capabilities has multiple definitions in literature, but covers the abilities of a company to integrate, reconfigure, create, and disseminate resources that are perceived as crucial to a firms adaptation to its environment (Eisenhardt & Martin, 2000; Teece, 2007). For the highly novel types of innovation, such as radical and (potentially) disruptive innovation, knowledge management were found to have an even stronger effect on long term performance of a company through its ability to support the creation and use of dynamic capabilities, than directly. These findings are well in line with the observations by (Benner & Tushman, 2003) that static processes are largely counter-productive when attempting to engage in exploratory innovation activities as the processes that make an incumbent company

perform well in its current context become the primary barriers to adaptation in the next context. The knowledge management infrastructure supports dynamic capabilities through enabling processes of knowledge evolution, which ultimately results in improved operational capabilities (Cepeda & Vera, 2007; Pavlou & El Sawy, 2010; Zollo & Winter, 2002). Where dynamic capabilities are the means by which an organisation adapts to a changing environment, the operational capabilities are the means by which an organisation is earning it's living on a daily basis (Cepeda & Vera, 2007). The research behind dynamic capabilities has been fragmented for many years and persists to be divided into several camps, which has prevented a convergence on precise definitions and classifications (Peteraf et al., 2013). Therefore, a specific focus was put on how dynamic capabilities were accumulated and used on the level of the engineering design team, which helped resolve the issue of dynamic capabilities often being defined in ambiguous ways, which makes precise classifications a very challenging endeavor (Eisenhardt & Martin, 2000; Peteraf et al., 2013). By focusing on accumulation and use of dynamic capabilities together with the form in which they are embedded into the organization is consistent with the dual focus on accumulation and use of knowledge found in literature that classifies an organization's knowledge resources as intellectual capital (e.g., (Bontis, 2001; I-Chieh Hsu & Sabherwal, 2011; Subramaniam & Youndt, 2005). According to Subramaniam & Youndt (2005), considering different aspects of intellectual capital offers scholars a means to parsimoniously synthesize the approaches through which knowledge is *accumulated* and *used* in organizations. Since Galbraith (1969) originally defined intellectual capital as the (intangible) difference between a company's actual value and its book value, a plethora of definitions have evolved (see (Bontis, 2001) for a review). However, as many of these definitions were developed for specific contexts and evidence from the social sciences, Mika (2005) suggests that concepts of knowledge may be contextually bound; thus, we chose to follow the definitions proposed by Subramaniam &

Youndt (2005). These were developed specifically to assess the effect of intellectual capital on innovation. Following the general consensus in the literature on intellectual capital, (Subramaniam & Youndt (2005) defined three separate aspects of intellectual capital:

- *Human capital* is defined as knowledge, skills and abilities residing with and utilized by individuals.

- *Organizational capital* is defined as institutionalized knowledge and codified experience residing within and utilized through databases, patents, manuals, systems, and processes.

- *Social capital* is defined as the knowledge embedded within, available through and utilized by interactions among individuals and their networks of interrelationships.

The intellectual capital framework provides the starting point for classifying the dynamic capabilities of an organisation that the design-teams are contributing to in the organisation.

2.4   Synergies between management and design research

The synergies between management research and design research are significant as both have been attempting to tackle certain identical innovation-related issues from different perspectives for years. For example, finding efficient processes for developing products has been a common interest between the two groups for decades (see, e.g., (Cooper & Edgett, 2008; Pahl et al., 2007). The phenomena studied in the two fields are typically multilevel, indicating that several levels of analysis and theory creation are nested within one another; for example, an individual working in a team who is working in a department (Hitt, Beamish, Jackson, & Mathieu, 2007) concludes, from a review of the levels of research in management research, that most management problems involve multilevel phenomena, although most management research uses a single level of analysis. Furthermore, as a means to improve the quality of management research, (Hitt et al., 2007) recommends cross-disciplinary collaboration in studies of multidisciplinary topics and increasing attention on bottom-up effects in macro-level studies. From the design research field, (Blessing & Chakrabarti, 2009) describes the act of design as a multifaceted phenomenon – similar to the multilevel view – involving *people* developing a *product* using a *process* that involves a multitude of *activities* and *procedures* and a wide variety of *knowledge, tools and methods* and acting within an *organization* and a *micro-economic* and *macro-economic* context.

Potential synergies between the two fields is demonstrated by recent literature, e.g., (Boland & Collopy, 2004), in which the concept of managing as designing is explored and the ways in which designers handle radical uncertainty and ambiguity are used to inspire new decision-making practices, among other things. Another example of potential synergy is (Beckman & Barry, 2007), who aims to embed design thinking into innovation management; this idea is also currently being advocated by design consultancies such as IDEO, which has reported that management support has become a central service, as opposed to traditional product

design (Brown, 2008). However, not much research is currently being conducted across the boundaries of disruptive innovation management and design, which is exemplified by a review of the interplay between exploration and exploitation in which (Gupta et al., 2006) concluded that even though dynamic capabilities appear to be central for balancing exploration and exploitation, it remains unclear how these dynamic capabilities are created on the level of the individuals and teams involved in innovation. With the commonalities identified here and the common roots in post-World War II technology projects, it appears that crossing borders is possible and feasible. Examples of concrete areas that have been identified, in which the fields may learn from one another include the following:

- Research methodology: Management research has much to offer in terms of descriptive methods and traditions for creating and critically reviewing advanced descriptive frameworks. Conversely, design research has much to offer with respect to synthesizing support and problem-solving approaches for wicked problems based on conjecture and the co-evolution of problem and solution.

- Context and bottom-up effects: Management research offers a deeper understanding of the organizational and industrial context in which design is created, e.g., through the resource-based view of the firm and effects from competitive forces, whereas design research offers deeper insight into the bottom-up effects created by the interplay between designers, products and product contexts.

- Linking design and management prescriptions: From design research, processes and methods for handling ambiguity and wicked problems, in which the problem and solution co-evolve, are researched extensively. From management research, strategic planning for uncertain futures is researched extensively, e.g., in terms of flexible organizational designs, such as an ambidextrous organization or a learning organization.

2.5   Reflection on and synthesis of theory

From the historical view on design and innovation models, radical design process innovation appears to be correlated with large technological shifts in the system being designed – from integration with scientists, the establishment of new infrastructures, such as aerospace, and the change from technology push to market pull. It could therefore be predicted that another radical change to the design process is likely to arise in the near future because engineering design companies within various domains (not least the energy sector) are now facing the need to integrate societal concerns about environmental sustainability into their designs. This process requires the integration of knowledge domains and personnel not previously involved with engineering design, such as market regulators, politicians and, to a much larger extent than before, the social sciences. Thus, the loop of engineering design processes would return to where it originated after the Manhattan project: the energy sector.

The literature review supported the identified gap in literature by emphasizing:

- Sparse research is performed on the challenges that technological disruptive innovation poses to the design team in situations where the disruption is intentional.

- Studies on disruptive innovation in the literature are almost exclusively historical studies; limited real-time studies have followed disruptive innovation in the making.

- While several studies underline that process management may not be suited for supporting exploratory activities, research on practically applicable alternatives for team-level support tools is lacking.

- Several studies emphasize that dynamic capabilities are likely to affect a company's ability to balance exploration and exploitation; however, the team level origin of these capabilities is still largely unknown.

In addition, the literature review highlighted several important characteristics of the research question:

- Knowledge is essential to team-level studies of exploration and exploitation; in particular, diversity and depth in the design team appear to significantly influence the performance of the resulting innovation.

- Innovation is likely to be positively affected by a high degree of interplay between knowledge domains, which is expected to require facilitation in the form of human boundary spanners and/or boundary objects.

- For long-term innovation performance of a company, the knowledge management infrastructure is likely to be most valuable through its ability to facilitate the accumulation and use of dynamic capabilities.

Several essential models and charts for the further analysis resulted from the review and synthesis of literature. These provided the backbone of empirical study, where they were used in the following way: Table 2 was used to map innovation projects in terms of their innovation height, which provided the context of this research as presented in Figure 2. Table 6 was used to create the initial coding scheme through defining bins from which codes could be developed and the empirical findings coded. Besides the synthesised views, intellectual capital was used to provide a more operational view on dynamic capabilities and the boundary object theory was used as the theoretical underpinning for designing the prescription in the form of a boundary object. Together, these theories form the conceptual frame for this project as detailed in figure Figure 3.
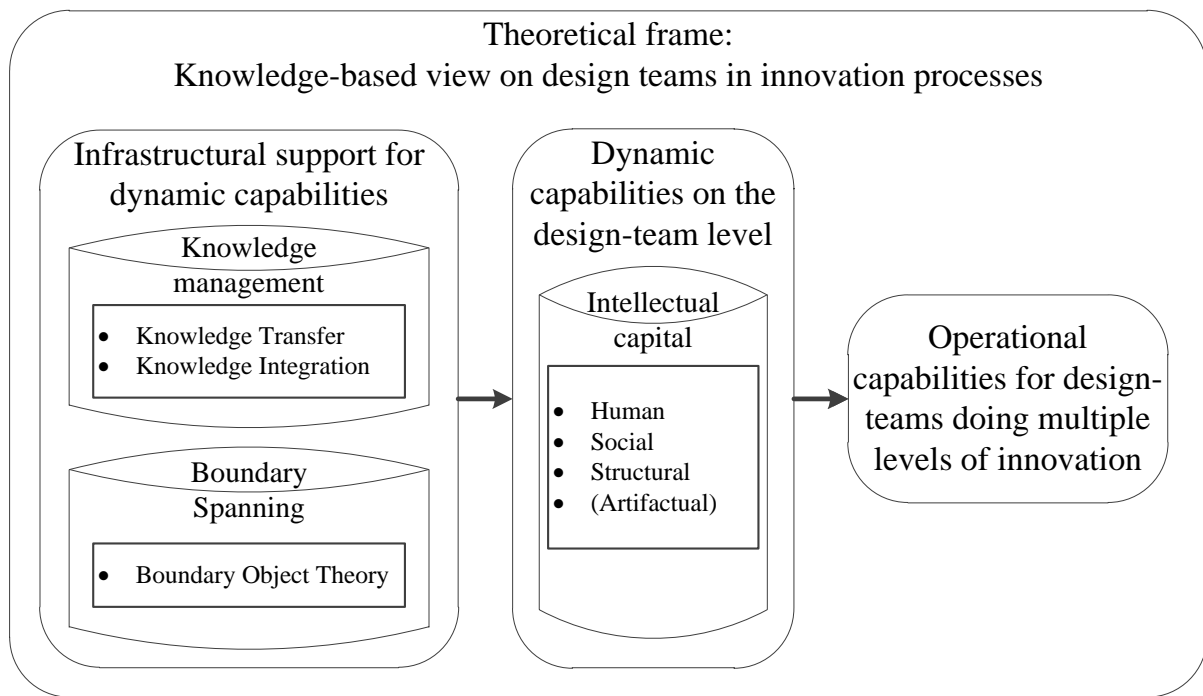
Figure 3: Conceptual framework synthesized from integration of the applied theory

As this shown in Figure 3, the knowledge based theories are core in this project and the innovation process theory informs about the context and desired outcome from the design-teams. The theoretical relationships between the concepts are that knowledge management with a specific focus on knowledge transfer and knowledge integration, together with boundary spanning forms the infrastructural support needed for dynamic capabilities to evolve. The boundary spanning theory has been singled out from the general knowledge management, as this is where the prescription contributes to the existing KM infrastructure. The infrastructure affects the dynamic capabilities directly, and these has been analysed through the lenses of the intellectual capital framework. In the framework, a fourth capital is shown in brackets, which was induced from the empirical result and added to the extant theory in paper 5. Finally, these dynamic capabilities affect the performance of design teams, through improved operational capabilities. All of this happens within the context of the innovation process.

3 Methodology

This chapter presents the research design and how the research was conducted, with the purpose of providing a collected overview. Further details on the methodology applied in each phase can be found in the corresponding Papers. First, the research framework is presented with an overview of methods and datasets used within each phase of the study, and this overview is followed by a description of each separate phase.

3.1 Research Design

Organizational management research and engineering design research both address mostly multilevel phenomena, i.e., research problems that span multiple levels of the organization, both in terms of analysis and theory creation. This multilevel nature requires that methodologies and methods are carefully selected to craft a research approach providing the necessary insight into the phenomenon while keeping the researcher's focus trained on the specified levels. During the study, it was found that the field of management is rich in rigorous methodological descriptions but that these descriptions lack the ability to contain conjecture-based synthesis activities. Conversely, the design research field generally lacks scientific rigor but offers methodologies in which the synthesis activities are supported explicitly (Blessing & Chakrabarti, 2009). To address this discrepancy, methods from both fields were used together. Research questions were aimed at dual purposes because an understanding of the innovation process and the tools for improving it were within the scope of this research, but the central contribution lies within design. Therefore, the design research methodology (DRM) was chosen as the framework for the research design because its overall objective is *"the formulation and validation of models and theories about the phenomenon of design, as well as the development and validation of support founded on these models and*

theories, in order to improve design practice, management, education and their outcomes"

(Blessing & Chakrabarti, 2009).
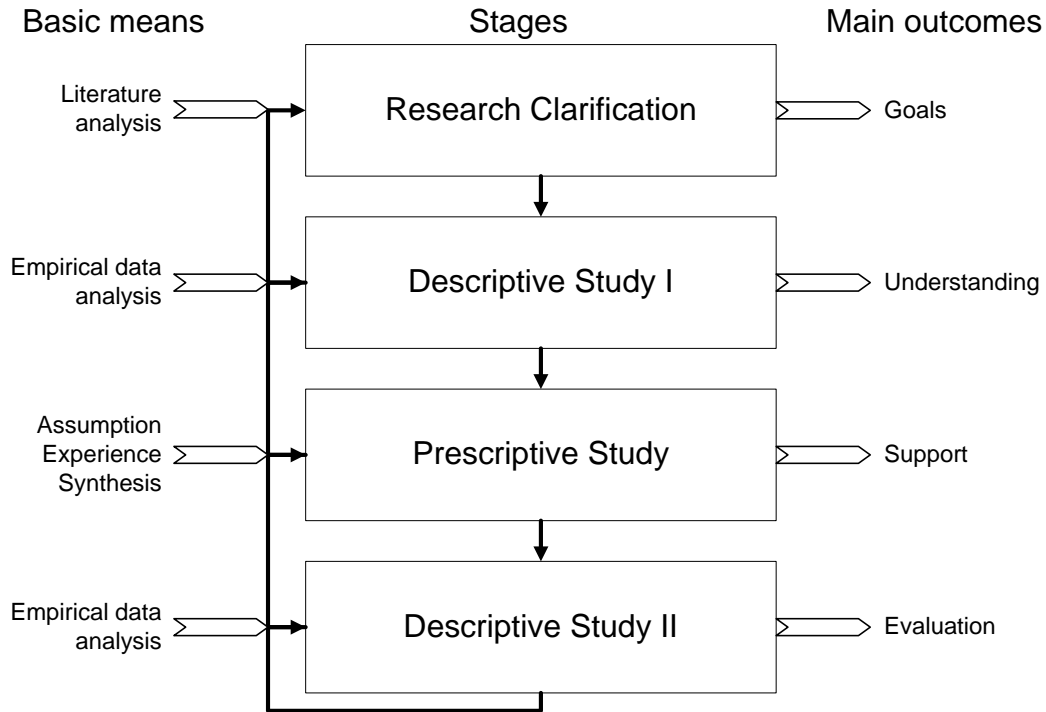
Figure 4: Design research methodology framework

The framework prescribes a generic approach for conducting rigorous research through a

series of iterative steps with methods and guidelines to support it (see Figure 4). Although it

is rare for a research project to go through all its stages in practice, it remains essential for

design researchers to be aware of the entire process. In descriptive study I, it should be

considered how to create a prescription from the understanding created in the study, and the

design researcher should consider how to validate the support while developing the

prescription. This study was taken through the entire process, from research clarification to

validation of the proposed support in descriptive study II. The framework was populated with

specific research methods that were driven by the research questions, the results from the

preceding stages and the expected requirements from the next stage (see Table 8).

Table 8
Characteristics of the research phases in this study, in line with the design research methodology

Characteristic	Research Clarification	Descriptive study 1	Prescriptive Study	Descriptive study 2
Aim	To clarify goals relevant to research and DONG Energy. Confirm prescriptive approach.	To understand the knowledge-based challenges and mechanism for supporting designers in innovation	To develop support for design of innovations via participatory design	To evaluate the support via experiments as well as live implementation
Context	Oil equipment company DONG Energy (DE)	DONG Energy	DONG Energy Energy Network	DONG Energy DTU and Stanford University
Case	DONG Energy Innovation centre Oil equipment company	Innovation centre	Innovation centre	
Units of analysis	Innovation project teams Innovation centre (department)	Innovation project teams Innovation centre (department)	Innovation project teams Innovation centre (department)	Innovation project teams Innovation centre (department)
Collection methods (datasets used)	20 Semi-structured interviews Informal meetings and discussions 3 formal meetings	6 Semi-structured interviews 486 hours participant observations 2 Workshops	Interaction with users through participatory design	35 Structured interviews 2 Experiments
Primary Data sources	20 employees from oil equipment company 15 Innovation developers (DE) 3 Innovation directors (DE)	80+ R&D employees (DE) 5 Innovation directors (DE) 22 Innovation developers (DE)	12 Energy network members 12 Innovation developers (DE) 40+ R&D employees (DE)	37 Concepts, generated in experiments with 22 students in 11groups. 35 Dong Energy employees
Role of researcher	Observer and interviewer	Observer Participant observer (rarely)	Full participant	Observer Analyst
Analysis methods	Postdefined codes	Predefined codes Postdefined codes	Participatory design (Synthesis method)	Descriptive statistics Predefined codes

3.2 Research clarification (Papers no. 1 and 2)

The first step in the Design Research Methodology (DRM) framework is research clarification, which aims to set the goals for the project in a way that simultaneously achieves scientific novelty and industrial value. For this study, the research clarification was based on a two-month-long pre-study within DONG Energy (a Danish energy utilities company), conducted in tandem with a literature review, to create research questions that ensured scientific novelty and long-term commitment from DONG Energy. The research question discussed in the introduction was established during this phase.

The approach taken was in line with the DRM guidelines, in which the focus is on using literature reviews as the primary method for supporting clarification. However, in this study, the literature review was combined with an analysis of data collected at Aker Solutions (an oil equipment manufacturer) and the pre-study at DONG Energy. This process led to the following success criteria:

1. Improving the quality of innovation concepts and /or activities that are understood as perceived quality by the decision makers. (This proxy was necessary because the lead-times of innovation projects in the sector are beyond the length of a PhD project.)

2. Improving the management of the innovation by providing a model or description of knowledge-related issues that are of central importance during innovation projects.

3. Improving the implementation of design and innovation support methods.

These criteria were found to be challenging to measure; hence the study started by establishing a way to measure these criteria, which is reported in Paper no. 2 and 5. The rationale for selecting a participatory design approach is reported in Paper no. 1 and 5 and was aimed at success criterion 3, to improve the implementation of support methods.

3.3 Descriptive study I (Papers no. 2, 3, and 4)

The second step in the DRM is descriptive phase I, which aims to provide a deeper understanding of the phenomenon studied and to explain that understanding in terms of models and narrative explanations, for example. In this project, the descriptive study was conducted as a cross-sectional study, which is further detailed in Paper no. 3, and then longitudinal study, which is further detailed in Paper no. 4.

Given the sparse existing literature on the subject of the team-level creation of capabilities and the need for a rich understanding of the innovation process, an inductive research design was chosen. This design was based on a single case study with multiple embedded units of analysis, i.e., six innovation projects (see Figure 5, 3rd quadrant). The embedded design improved the likelihood of creating a rich and accurate theory about the phenomenon, while the single case study sacrificed statistical generalizability in favor of richer detail (Yin, 2002). Furthermore, sampling within one firm had the advantage of controlling for firm-level factors, such as incentive schemes, corporate culture, national culture and social ties (Martin & Eisenhardt, 2010). The company setting was required to fulfil three requirements. First, the innovation process had to be observable in real time over an extended period. Second, an incumbent company was required that was trying to adapt to changing environments. Third, the process of creating innovation capabilities had to be transparent and on-going, making a company in the nascent stage of building new innovation capabilities preferable. DONG Energy was found to meet all of these criteria. First, the company started several innovation projects in response to the societal need for sustainable energy and allowed unrestricted access to observe their projects. Second, the company's history goes back to the time when oil and electricity were introduced into the Danish society; currently, DONG Energy is trying to drive technological disruption by following a strategy that is intended to convert at least 85% of its energy production to sustainable sources by 2040. Third, the company was

forming an innovation centre simultaneously with the start of this study; this centre was in charge of developing the company's innovation capabilities, which provided an opportunity to study the nascent stage of developing innovation capabilities. Therefore, this case fulfils the requirements that a single case study is appropriate when the process of interest is transparently observable and when the case itself is extreme or unique (Eisenhardt, 1989; Yin, 2002). Thus, the innovation centre was the case for studying dynamic capabilities in innovation, and the company became the context. To sample the units of analysis, snowball sampling was used to gain access to the six primary projects (see Figure 5, 3rd quadrant).
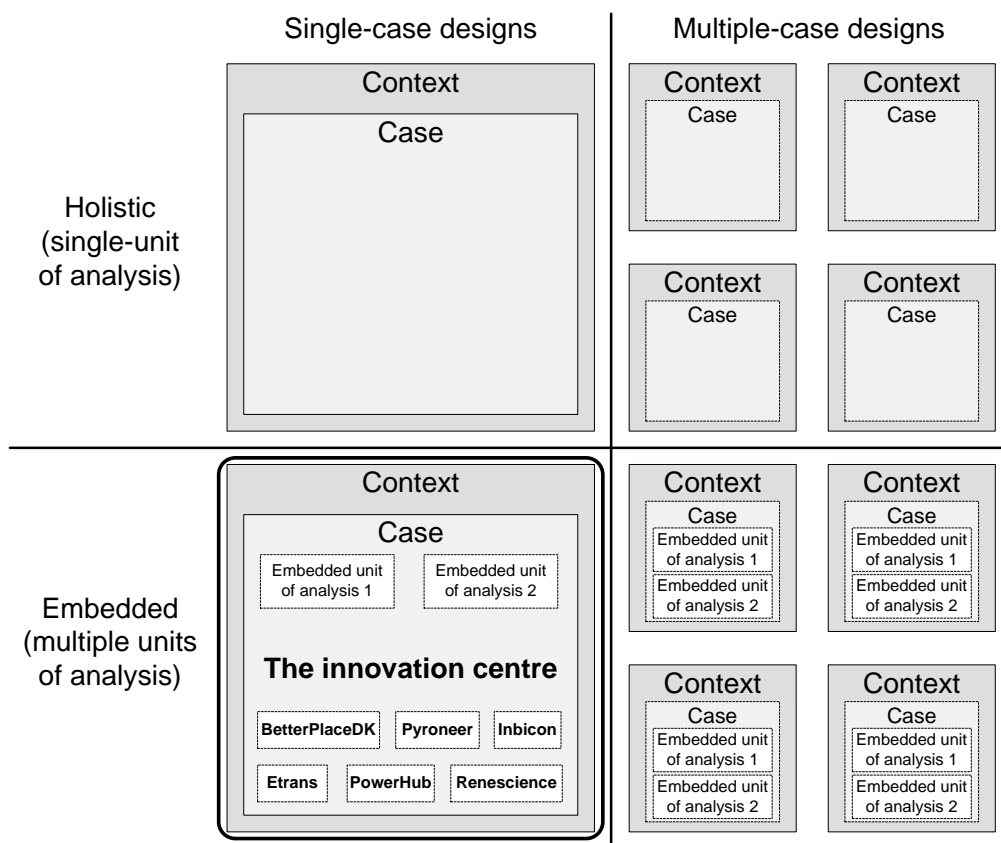
Figure 5: Types of case study designs. This study is marked in the 3rd quadrant with the six projects as embedded units of analysis (model adapted from (Yin, 2002))

The innovation centre was organised as an independent multi-disciplinary unit. They had specialists in all phases of innovation from front-end to commercialisation and specialists within regulatory innovation, business models, and technology. The technological specialisations covered in the centre were mainly focused around grid control and power

integration, biotechnology, and oil-refinement. During the course of the study, the innovation centre was restructuring several times in terms of competencies. Within this set-up, all the six projects that were followed in the study were aiming at integrating state of the art knowledge from other disciplines into the energy sector as well as technological development from scratch, these included new generations of enzymes, mechanical equipment for the (bio) refinery industry, and algorithms for controlling and integrating units into smart-grids. The innovation teams were self-governing, except for meetings during large stage-gates, such as the critical go-/no-go decision when moving from front-end to the formal product development phases. The projects were deliberately outside the scope of any of the internal business units and sometimes even at odds with them. In terms of resources, all projects started with a core team from the innovation centre members and used external consultants and partners when complementary resources were needed. When the projects moved closer to transition from front-end to product formal product development, they started to hire project staff from the business units who were assessed to be most likely to see the innovation as an opportunity more than a threat.

In particular, we followed six projects that were run by the innovation centre, these were:

1) *Inbicon* aims to develop mechanical technologies required to produce 2nd generation bioethanol from straw on an industrial scale. The technology is based on commercially available enzymes and builds on a long prehistory of knowledge generated from the pre-treatment of straw for combustion.

2) *Renescience* aims to develop the mechanical and enzymatic technologies that are needed to pre-treat normal household waste from a landfill to synthesize gas that is comparable to natural gas. The technology builds on the knowledge generated within the Inbicon project.

3) Pyroneer aims to create synthesis gas on a large scale via the thermal gasification of a wide range of biomass sources, including types of biomass that are not suitable for enzymatic processes. The Pyroneer project builds on knowledge from thermal power plants and employs a patent that was acquired externally from a researcher.

4) Powerhub/VPP aims to balance the electricity grid via the rapid and efficient control of small units that either produce or use electricity by bundling them into virtual power plants. Powerhub/VPP builds on knowledge obtained from the generation of large amounts of wind power since the 1980s.

5) BetterplaceDK aims to develop standards and infrastructure for charging electric vehicles in DK and through Betterplace in the rest of the world. BetterplaceDK builds on knowledge regarding grid integration and balancing services as well as the external partnership with Betterplace.

6) Etrans aims to develop the value chain for electric mobility and to explore concepts related to electric mobility services for end-users. Etrans builds on knowledge regarding demand-profile modeling and sales as well as an external consortium-collaboration with 14 other industrial actors.

Table 9: Mapping of projects in technological innovation types

First level	Second level	Projects
(Potentially) disruptive innovation		Etrans, BetterplaceDK, Renescience
Sustaining innovation	Radical innovation	Powerhub/VPP, Inbicon
	Incremental innovation	Pyroneer

In Table 9 a mapping of each project in terms of its innovation height as described in the literature review is provided. The projects covered the entire spectrum of innovation height (see Table 9), thus the theory developed from the understanding of these projects is aimed at

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a broader innovation imperative and not as such an exploration of one specific type of innovation. The mapping of disruptive innovation is done in terms of "potentially disruptive" based on the projects innovative ability to result in disruption the company itself and society at large. However, as this disruption is yet to take place, this mapping can very well change in the future as markets and technologies develop. These projects formed the main data collection together with data from the innovation centre described in the next sections.

3.3.1 Data collection methods

From these projects, and from the innovation centre itself, four primary dataset were collected: six interviews, a workshop facilitated by the researchers, an internal workshop and 486 hours observations. We collected data from a number of different sources, including interviews, observations, workshops and archival data from the corporate intranet to corroborate facts. Using four data sources allowed us to triangulate the sources, which improved the robustness of our resulting theory (Jick, 1979). The four primary data sources were:

- 486 hours of observations from the innovation center and six projects
- One workshop organized by the case company
- One workshop organized by the authors
- Six semi-structured interviews with project members from the innovation center.

The archival data we used as secondary data and mainly to corroborate facts such as dates of events. In this manner, we combined real-time data from observations with retrospective data from the other sources, enabling efficient collection of data on multiple projects and maintaining a deep understanding of how events evolve over time (Leonard-Barton, 1990). The characteristics of these methods are described in the following sections. For more detail on the collection methods and mitigation of bias, please refer to Papers 3 and 4. Furthermore, an audit-trail of the data collection and the interview guide is provided in appendices 3 and 4.

Across collection methods and sources, steps were taken to strengthen the quality of the data, guided by (Miles & Huberman, 1994) (see Table 10).

Table 10: Circumstances weakening and strengthening the quality of the data (Miles & Huberman, 1994)

Circumstances for stronger data	Circumstances for weaker data
Collected late in study, or after repeated contact	Collected early, during entry
Seen or reported firsthand	Heard secondhand
Observed behavior, activities	Reports or statements
Field-worker is trusted	Field-worker is not trusted
Collected in informal setting	Collected in official or formal setting
Respondent alone with fieldworker	Respondent is in presence of others, in group setting

With the combination of collection methods described here, the first five circumstances were obtained for the category of stronger data. The last circumstance proved to be more challenging because much of the data was collected in plenary sessions, such as meetings. To address this issue, time was spent alone with participants immediately after the meetings, during which they were encouraged to provide their own interpretations of the meetings.

The observations were conducted with the researcher in the role of a participant observer; the researcher would contribute to tasks with minimal influence on the informants, such as writing minutes and presentations (Patton, 2001). To maintain a consistent form of data collection, all observations were documented in field notes using the following template, based on the works of (Blessing & Chakrabarti, 2009; Emerson, Fretz, & Shaw, 1995; Hales, 1987; Lofland, 2006):

1. Metadata – observation no., date, duration, participants and location.
2. Interaction type – chance meeting, dialogue, work session, formal meeting, larger meeting.
3. Topic of the interchange – for example, the innovation process, decision processes, technologies, regulations, and the future of society.
4. Objective observations – who said what to whom, actions, and order of events, with distinctions made between quotations, paraphrasing, and summaries.
5. Reflections on the usefulness of theory, organizational influences, personal reflections, and methodological reflections.
6. Other – most often used for personal reminders of things to do or not to do.

Through this approach, a total of 486 hours of data was collected in 1,344 pages of field notes with over 100 different participants (see Table 12).

The workshops provided information about employee experiences across a wide range of past projects, and all of the statements made by the informants were validated and/or corrected by other participants. Two workshops were used for this phase of the study, one facilitated by the researchers and one by the company, with the researcher as passive observer (see Table 11).

Six semi-structured interviews were conducted, lasting between one and one-and-a-half hours each. The interview guide was based on the literature and was followed during the interviews, but interviewees were allowed to expand on their answers, and the interviewer was allowed to probe further into topics as they arose. The questions spanned the following four categories: 1) personal networks and their function; 2) the interviewee's understanding of innovation, knowledge, and decision making; 3) personal narratives related to knowledge

flow and decision-making processes; and 4) experience with the methods and tools used for

making decisions, innovation support, and knowledge management.

Table 11
Details on the data collection workshops

Characteristics	Workshop 1 Knowledge in Innovation	Workshop 2 Balancing Structure and Creativity
No. of participants	23 people in 4 groups	54 people in 10 groups
Participants	Innovation function at management, project management and specialist level	Innovation function at management, project management and specialist level
Topic(s)	How may knowledge be structured and made accessible for innovation? How may knowledge-sources be identified and activated in innovation? What are the criteria for evaluating the quality of knowledge management methods?	Create ideas for enhancing innovation by balancing structure and creativity.
Duration	7 hours	6 hours
Preparation of participants	20 minute introduction to KM in innovation and 3x5 minutes explanation of tasks.	45 minute lecture on a mental model describing roles of structure and creativity in innovation.
Staging	Research group staged and facilitated	Case company staged, consultant facilitated
Facilitation	Structured around the three topics with prescribed brainstorm approach and discussions in plenum	Open-ended facilitation, with groups choosing their own methods, presentations in plenum.
Collection of data	Produced material, structured by the participants, captured on post-it notes, flipcharts and posters.	Produced unstructured material captured on large post-it notes with explanations
Amount of data	189 codeable segments	259 codeable segments
Treatment of data	Coding	Coding

Period	Hours of Observations	Central Observed Activities	Significant Events	Central Data on Projects
Quarter 1 2009	50,25	IC department meetings Seminar on strategic themes Internal relationship mapping Project work	IC is founded, Discover, incubate, accelerate process-model IC Pyramid structure	Inbicon, Better place DK, PowerHUB
Quarter 2 2009	73,25	IC department meetings Cleantech collaboration with BU Workshops on new design methods R&D seminar "from ideas to reality" Project work	The Etrans project starts Marguerite structure Effects from financial crisis	Etrans, Renesecience, Inbicon, Better place DK, PowerHUB
Quarter 3 2009	18,5	IC dept. meetings ETrans kick-off reflection Project work		Etrans, Renescience, Pyroneer, Inbicon, Betterplace DK, PowerHUB
Quarter 4 2009	29	IC department meetings Infusion of design methods from etrans Intranet strategy meetings Project work	COP 15 in Copenhagen ~300 people laid off	Etrans, Renescience, Pyroneer, Inbicon, Betterplace DK, PowerHUB
Quarter 5 2010	59,5	IC department meetings Collaboration with HR on processes Eflex project started with methods and data from etrans Project work		Etrans, Renescience, Pyroneer, Inbicon, Betterplace DK, PowerHUB
Quarter 6 2010	42	IC department meetings Reinventing processes of IC Reigniting the Etrans project Project work	New top manager Strategic basket process IC wheel structure	Etrans, Renescience, Pyroneer, Inbicon, Betterplace DK, PowerHUB
Quarter 7 2010	27	IC department meetings Workshop on global innovation leadership Project work		Renescience, Pyroneer, Inbicon, Betterplace DK, PowerHUB
Quarter 8 2010	19	IC department meetings Meetings with R&D from BU's Project work		Renescience, Pyroneer, Inbicon, Betterplace DK, PowerHUB
Quarter 9 2011	14,5	IC department meetings Project work	Thermal engineering is sold Fukushima accident New funding process	Renescience, Pyroneer, Inbicon, PowerHUB
Quarter 10 2011	70	IC department meetings E2G open data sharing created Introduction of virtual collaboration Project work		Renescience, Pyroneer, Inbicon, PowerHUB
Quarter 11 2011	40	IC department meetings Foresight collaboration with Siemens Project work	Inbicon in media-storm	Renescience, Pyroneer, Inbicon, PowerHUB
Quarter 12 2011	20	IC department meetings IC + BU's research strategy workshop Project work	Betterplace DK in media storm	Renescience, Pyroneer, Inbicon, PowerHUB, Etrans
Quarter 13 2012	19	IC department meetings Seminar on innovation process management Project work	Bottom-up stage-gate IC Bubble structure	Renescience, Pyroneer, Inbicon, PowerHUB, Etrans

3.3.2 Data analysis

We established our initial coding scheme from a theoretical framework that combined innovation process support and intellectual capital. However, as themes emerged from the data, we added codes, and sub-codes, by moving back and forth between the empirical data and theory. This process resulted in three coding-schemes (knowledge, decision, and foresight) with 20 codes and numerous mutually exclusive sub-codes (see Table 15 and Table 16)

Firstly, we created an initial coding scheme by eliciting codes from applying the knowledge-based view on innovation processes, thus the initial coding scheme corresponds to Eisenhardt's (Eisenhardt, 1989) a priori constructs and Miles & Huberman's (Miles & Huberman, 1994) conceptual framework. The use of an initial coding scheme connected the study closely to existing theory, through the set of basic codes and categories shown in the literature review (see Figure 6).

Secondly, we segmented our four data-sets independently and coded each dataset according to the common coding scheme (see coded examples in Table 15 and Table 16). For all of the data-sets, segments were coded into multiple codes related to knowledge, decision-making and foresight in order to infer the empirical relationships between these constructs in the final analysis (Miles & Huberman, 1994).

The data from the workshops were segmented so that each "suggestion" captured during the workshop became a segment. To each segment, contextual data were added such as the question or task given to the participants, and the classifications made by the participants during the workshop (see Table 13).

Table 13: Example of six contextualized and coded data segments from the workshops

Specific suggestion on post-it notes from participants	Skill-upgrading of current employees in business understanding	"Numskull Jack" (Klods Hans) - Be yourself	Best practice transfer from other large companies e.g. Novozymes	Concern-understanding across the concern via e-learning	Upgrade and internally prioritize networks	Concern management sponsorship
Question / task posed to the participant	How can the knowledge domains be structured and made accessible?	Presentation of the Idea diamond and common language for innovation-task: develop ideas for enhancing Innovation	How can the knowledge domains be structured and made accessible?	How can the knowledge domains be structured and made accessible?	How can the knowledge domains be structured and made accessible?	What are the requirements we need to evaluate the methods against? - And how should the requirements be measured?
Mapping of suggestion done by participant	Organisational structure+ Personalisation+ Access to knowledge	Specific situation of using mud as sauce mentioned	Organisational structure+ Personalisation+ access to knowledge	Organisational structure+ Personalisation	Personalisation+ repository, not social network	Requirement, connected to challenge site
Codes (knowledge)	**Sub-codes (knowledge)**					
Innovation Phase	All Phases	0	Front-end	All Phases	All Phases	0
Exploitation of knowledge	Dissemination	0	Collecting	Dissemination	Dissemination	0
Exploration of knowledge	Integrating	Experimenting	Integrating	Monitoring	Reflection	0
Barriers for knowledge transfer	Interpretation difference	Pre-conception of knowledge Quality	Accessibility of source	Accessibility of source	Lack of common frame of understanding	Lack of mediation
Novelty of knowledge	Existing	Partly Known / Adapted	New to Firm	New to Org. Unit	New to Firm	0
Knowledge domain	Business model and processes	0	Business model and processes	All	All	All
Knowledge retention strategy	Create internally	Create internally	Get externally, keep	Spread and Keep	Spread and Keep	0

Hereby, the coder was assisted in interpreting the data as correctly as possible, by having an overview of not just the exact statement but also the context in which the statement was created.

The interviews were all transcribed and divided into a total of 619 segments, with a new segment beginning when an interviewee paused between utterances. Contextual information was added in the form of questions from the interview-guide and all interviews were coded as a single dataset.

The observations were segmented and coded in two separate cycles, due to the magnitude of the data-set. In the first cycle, all the field notes were coded in terms of the three codes of intellectual capital and during this process a fourth code (artifactual capital) was added as the three categories from theory were found to be insufficient for covering intellectual capital embedded into artifacts. This process reduced the dataset into 430 segments, each with a large subset of field-notes within. Contextual information was added in form of a timeline with significant events e.g. "the thermal engineering department sold off", corresponding to the timestamps on the 430 segments. The contextual information, as well as the original field-notes, was used for deeper clarification of segments when needed during the coding and interpretation of segments.

Thirdly, we developed the coding scheme further by analyzing the empirical data to verify or reject the initial codes and sub-codes and to create new codes and sub-codes. Recurring themes found in the four data-sets were identified through three primary code identification techniques: Repetitions, cutting and sorting, and similarities and differences, as all these techniques have been proposed to support both rich narratives (interview and observation data), and brief descriptions (workshop data) (Ryan & Bernard, 2003). These techniques are furthermore found to be appropriate for both verbatim data and field notes (Ryan & Bernard, 2003). This combined questioning and further development of the coding-scheme had the benefit of limiting the bias caused by forcing findings into a solely predefined coding scheme (Eisenhardt, 1989).

Initial coding scheme

Other Grouping Categories	Other Grouping codes	Exploration	Exploitation	Kind of expectation	Characteristics of DM in NBD	Metrics for assessing KM method quality

Data-driven changes

Final coding scheme

Categories	Across Groups				Group 1: Knowledge Management in New Business Development (NBD)					Group 2: Decision Making in New Business Development (NBD)					Group 3: Role of expectations in New Business Development							
Codes	Intellectual Capital	NBD Phase	Innovation Purpose	Knowledge type	Exploitation	Exploration	Barriers for knowledge Transfer	Novelty of Knowledge	Knowledge Domain	Knowledge retainment strategy	Decision Practices	Characteristics of DM Behaviour in NBD	Centralised / Distributed decisions	Behaviour of Decision Object	Temporal mode of knowledge	Knowledge Source	Model of the future	Temporal mode of expectation	Acceptance degree	Relationship to expectation	Creation of expectation	Role of expectation
									All													
									Business model and processes													
							Pre-conception of knowledge Quality		Development funding													
							Ease of Access		Internal Alliance creation		External "authority"											
							Deliberate restricted access		External Alliance Creation		Perusade network to support											
					Concentration		Lack of mediation		Regulatory environment		Core capability utilisation											
					Dissemination		Cause for interaction	New to Org. Unit	Insights into user's world		Business model Alignment									Normative		
	Human Capital	All phases			Externalising	Reflection	Lack of common frame of understanding	New to World	Dynamics of the market	Spread and Keep	Fit requirements	Explicit Personal				Internal Political				Desired		
	Structural Capital	Project (Open ended)	Business Creation	Temporary Static	Collecting	Monitoring	Accessibility of source	New to Firm	Technical Characteristics	Create internally	Fit expectations	Explicit Social	Centralised	Hybrid	Past / Experience	Internal Specialist		Near Future	Personal	Indifferent		Strategist
	Relational Capital	Transition (Pre to Pro)	Strategic positioning	Dynamic (permanently)	Cod. Dissemination	Experimenting	Knowledge Level Distance	Partly Known / Adapted	Synergies with energy system	Get externally, keep	Best requirements fit	Implicit Personal	Intermediate	Irrational	Current / Context	External Political	Determinist	Mid Future	Social	Feared	Method	Initiator
	Artefactual Capital	Project (G - Directed)	Knowledge Building	Static (permanently)	Per. Dissemination	Integrating	Interpretation difference	Existing	Energy resource reliance	Consult external source	Best expectations fit	Implicit Social	De-centralised	Rational	Future / Goals	External Specialist	Constructivist	Far Future	Codified	Threatening	No Method	Opponent

Figure 6: Changes from the initial coding scheme to the final coding scheme

Fourthly, we checked the reliability and validity of our constructs in two different ways: To test for the reliability of the coding, we used the kappa test developed by (Cohen, 1960), and to control the validity of our constructs, we presented them to the head of the innovation center. All of our data were coded by one person, hence we checked the reliability of the coding with a second coder by applying (Cohen, 1960)'s Kappa test. We gave a second coder the definitions of the codes together with an example of each code. Then we asked the second coder to code a sample of 20 segments from each workshop, 20 segments from the interviews and 20 segments from the observations. Based on the comparison of the 80 lines of coded samples with the original coded lines, we calculated the frequency of agreement between the two coders while calibrating for the frequency expected to occur by chance. Finally, we compared the results to those found in (Bakeman & Gottman, 1997) to draw the following conclusions: 0.4 – 0.6 was considered fair, 0.6-0.75 considered good, and 0.75 – 1.0 considered excellent.

Table 14: Inter-coder reliability test

Coded Dataset	κ	Reliability
Workshop I	0,757	Excellent
Workshop II	0,671	Good
Interviews	0,600	Good/Fair
Observations	0,81	Excellent
Across Datasets	0,74	Good

We found that the Kappa values within and across all four data sets were satisfactory as there was generally good to excellent reliability, indicating reliable coding and little bias due to the coder. We found that the most reliable coding, categorized as *excellent*, was that of the observations, whereas the interviews were the least reliable, with a score of *good to fair*. From this comparison, we consider the results from the analysis reliable.

Table 15: Examples of coded segments from observations, interviews, and workshops.

		Data and metadata				Structural Codes			Codes Across Groups			Knowledge			
Data Point	**Quarter**	**Data**	**Data Type**	**Multiplier**	**Intellectual Capital**	**NBD Phase**	**Innovation Purpose**	**Knowledge type**	**Exploitation**	**Exploration**	**Barriers for knowledge Transfer**	**Novelty of Knowledge**	**Knowledge Domain**	**Knowledge retainment strategy**
Innovation Center	Q2	007: IC is a huge head with a very small body: much competence, but we need to mobilize int. +external muscle	Field Notes	6	Human Capital	Transition (Pre to Pro)	Strategic positioning	0	0	Integrating	Lack of common frame of understanding	New to Firm	External Alliance Creation	Get externally, keep
Innovation Center	Q10	003: We sold our assets in Norwegian hydro because IC failed to communicate to the deciders what would be important in the future	Field Notes	1	Structural Capital	Project (Open ended)	Strategic positioning	Temporary Static	Dissemination	Integrating	Lack of common frame of understanding	New to Org. Unit	Technical Characteristics	Spread and Keep
Innovation Center	Q4	002: IC is characterized by project work and cross organizational collaboration, which require knowledge sharing across all barriers to deliver fast enough results to keep up with competition.	Field Notes	7	Relational Capital	All phases	Knowledge Building	Temporary Static	Dissemination	Integrating	Lack of common frame of understanding	New to Firm	All	Spread and Keep
Innovation Center	Q3	002: It is essential for idea management that new ideas are brought in via (new) products and services	Field Notes	6	Artefactual Capital	0	Knowledge Building	Temporary Static	Externalising	Integrating	Lack of mediation	New to Firm	All	Create internally
e-Trans	Q4	001: We need less joint learning and more meritocracy, with KDS taking knowledge-merited leadership	Field Notes	6	Human Capital	Project (Open ended)	Knowledge Building	Temporary Static	Collecting	Integrating	Lack of mediation	New to Firm	Insights into user's world	Get externally, keep
e-Trans	Q6	It is seen as a challenge that flexibility concepts in general are placed right between the S and the D, where a Chinese wall is legally required	Field Notes	4	Structural Capital	Project (Open ended)	Knowledge Building	Temporary Static	Dissemination	Experimenting	Lack of common frame of understanding	New to Firm	Dynamics of the market	Get externally, keep
e-Trans	Q4	During both KDS and Andy WS a large effort is put into getting the Business Units (Sales & Distribution + Power) to participate	Field Notes	6	Relational Capital	Project (Open ended)	Knowledge Building	Dynamic (permanently)	Collecting	Integrating	Pre-conception of knowledge Quality	New to Firm	Internal Alliance creation	Consult external source
e-Trans	Q2	008: "teknik" becomes technology when "logos" is added through human interaction (activated "teknik")	Field Notes	2	Artefactual Capital	Project (Open ended)	Knowledge Building	0	0	0	0	0	0	0
Workshop 1	-	A Good phonebook on the VITAL	Transcript	-	-	All phases	-	-	Per. Dissemination	Monitoring	Accessibility of source	Partly Known / Adapted	All	Spread and Keep
Workshop 1	-	Technical Career Path	Transcript	-	-	All phases	-	-	Concentration	Experimenting	Lack of mediation	New to Firm	Technical Characteristics	Create internally
Workshop 1	-	Rotation of employees between projects	Transcript	-	-	Project (Open ended)	-	-	Per. Dissemination	Integrating	Lack of common frame of understanding	New to Org. Unit	All	Spread and Keep
Workshop 1	-	Minimal use of resources during implementation	Transcript	-	-	All phases	-	-	0	0	0	0	0	0
Workshop 2	-	Anchoring of "freedom" in management / Processes	Transcript	-	-	Project (G - Directed)	-	-	0	0	0	New to Org. Unit	Business model and processes	Create internally
Workshop 2	-	Get concrete activities and budget for working consciously with governance structures	Transcript	-	-	All phases	-	-	0	0	Accessibility of source	New to World	Development funding	Create internally
Workshop 2	-	Differentiate between preject and project: We need open relationships in the preject and closed relationships in the project	Transcript	-	-	Transition (Pre to Pro)	-	-	Cod. Dissemination	Integrating	Lack of common frame of understanding	New to Org. Unit	Business model and processes	Spread and Keep
Workshop 2	-	Diversity creates more innovation but requires openness - learn to listen in this situation	Transcript	-	-	Project (Open ended)	-	-	Collecting	Integrating	Lack of mediation	New to Org. Unit	All	Create internally
Interviews	-	So, it is more like they feel like they (the business units) are doing us a kind of favor by participating with their knowledge, and **I** would like it to be pull from them.	Transcript	-	-	All phases	-	-	Collecting	Integrating	Lack of common frame of understanding	Partly Known / Adapted	0	0
Interviews	-	First of all we have SCANNED the market, we have taken different segments: farmers, pig farmers and cow farmers and large hotels and school and public administration. A LOT of, what kind of energy they are using, district heating, electricity, oil, gas and () Did they pay all the taxes on energy and + if they didn't than we could pick up out the markets which are interested. Mainly the consumer who pay high + energy price.	Transcript	-	-	Project (Open ended)	-	-	Collecting	Integrating	Lack of common frame of understanding	Partly Known / Adapted	0	0
Interviews	-	Yeah. ++There has been a LOT of PEOPLE COMING IN AND COMING OUT for the up-start meeting.	Transcript	-	-	Project (Open ended)	-	-	Collecting	Integrating	0	New to Org. Unit	Internal Alliance creation	Spread and Keep
Interviews	-	And I have been talking about these routine meetings with POWER and PARTNERSHIP management which is very important part of knowledge management, I would say because we have to know what's going on, what's coming and what's going to be installed in the production units for green electricity and things like that.	Transcript	-	-	0	-	-	Collecting	Integrating	Accesibility of source	New to Org. Unit	Business model and processes	Spread and Keep

Table 16: Examples of coded segments from observations, interviews, and workshops.

	Data and metadata			Structural Codes			Decision				Foresight							
Data Point	Quarter	Data	Data Type	Multiplier	Intellectual Capital	Decision Practices	Characteristics of DM Behaviour in NBD	Centralised / Distributed decisions	Behaviour of Decision Object	Temporal mode of knowledge	Knowledge Source	Model of the future	Temporal mode of expectation	Acceptance degree	Relationship to expectation	Creation of expectation	Role of expectation
Innovation Center	Q2	007: IC is a huge head with a very small body: much competence, but we need to mobilize int. +external muscle	Field Notes	6	Human Capital	Business model Alignment	Explicit Personal	0	0	Current / Context	Internal Specialist	0	Near Future	Social	Threatening	No Method	Opponent
Innovation Center	Q10	003: We sold our assets in Norwegian hydro because IC failed to communicate to the deciders what would be important in the future	Field Notes	1	Structural Capital	Fit expectations	Explicit Social	Centralised	Rational	Future / Goals	Internal Specialist	Determinist	Far Future	Codified	Indifferent	No Method	Opponent
Innovation Center	Q4	002: IC is characterized by project work and cross organizational collaboration, which require knowledge sharing across all barriers to deliver fast enough results to keep up with competition	Field Notes	7	Relational Capital	Business model Alignment	Explicit Social	Centralised	Hybrid	0	0	0	0	0	0	0	Opponent
Innovation Center	Q3	002: It is essential for idea management that new ideas are brought in via (new) products and services	Field Notes	6	Artefactual Capital	Fit requirements	Explicit Social	Centralised	Hybrid	Current / Context	Internal Political	0	Near Future	Codified	Normative	Method	Initiator
e-Trans	Q4	001: We need less joint learning and more meritocracy, with KDS taking knowledge-merited leadership	Field Notes	6	Human Capital	Core capability utilisation	Explicit Social	Intermediate	Irrational	Future / Goals	External Specialist	Constructivist	Far Future	Social	Normative	Method	Initiator
e-Trans	Q6	It is seen as a challenge that flexibility concepts in general are placed right between the S and the D, where a Chinese wall is legally required	Field Notes	4	Structural Capital	Business model Alignment	Explicit Social	Intermediate	Hybrid	Future / Goals	External Specialist	0	Mid Future	Social	Normative	No Method	Initiator
e-Trans	Q4	During both KDS and Andy WS a large effort is put into getting the Business Units (Sales & Distribution + Power) to participate	Field Notes	6	Relational Capital	0	0	0	0	Future / Goals	External Specialist	0	Far Future	Social	Normative	Method	Initiator
e-Trans	Q2	008: "teknik" becomes technology when logos is added through human interaction (activated "teknik")	Field Notes	2	Artefactual Capital	0	0	0	0	0	0	0	0	0	0	0	Initiator
Workshop 1	-	A Good phonebook on the VITAL	Transcript	-	-	0	0	0	Rational	Current / Context	Internal Specialist	0	Near Future	Personal	Desired	0	Initiator
Workshop 1	-	Technical Career Path	Transcript	-	-	Core capability utilisation	0	0	Irrational	Future / Goals	Internal Specialist	0	Near Future	Personal	Desired	0	Initiator
Workshop 1	-	Rotation of employees between projects	Transcript	-	-	Core capability utilisation	Explicit Personal	Centralised	Irrational	Current / Context	Internal Political	0	Near Future	Personal	Desired	0	Strategist
Workshop 1	-	Minimal use of resources during implementation	Transcript	-	-	0	0	Centralised	Rational	0	0	0	Near Future	Personal	Desired	0	0
Workshop 2	-	Anchoring of "freedom" in management / Processes	Transcript	-	-	Business model Alignment	Implicit Personal	Intermediate	Irrational	Current / Context	Internal Specialist	0	Near Future	Personal	Desired	0	Initiator
Workshop 2	-	Get concrete activities and budget for working consciously with governance structures	Transcript	-	-	0	0	Centralised	Rational	Current / Context	Internal Political	0	Near Future	Personal	Desired	0	Initiator
Workshop 2	-	Differentiate between preject and project: We need open relationships in the preject and closed relationships in the project	Transcript	-	-	0	Explicit Social	Intermediate	Rational	Current / Context	Internal Political	0	Near Future	Personal	Desired	0	Strategist
Workshop 2	-	Diversity creates more innovation but requires openness - learn to listen in this situation	Transcript	-	-	Fit expectations	0	De-centralised	Irrational	Future / Goals	External Specialist	Constructivist	Near Future	Personal	Desired	0	Opponent
Interviews	-	So, it is more like they feel like they (the business units) are doing us a kind of favor by participating with their knowledge, and **I** would like it to be pull from them.	Transcript	-	-	**0**	Implicit Social	De-centralised	**0**	**0**	Internal Political	**0**	**0**	**0**	**0**	**0**	Opponent
Interviews	-	First of all we have SCANNED the market, we have taken different segments: farmers, pig farmers and cow farmers and large hotels and school and public administration. A LOT of, what kind of energy they are using, district heating, electricity, oil, gas and () Did they pay all the taxes on energy and + if they didn't than we could pick up out the markets which are interested. Mainly the consumer who pay high + energy price.	Transcript	-	-	Fit requirements	**0**	**0**	Rational	Current / Context	External Specialist	Determinist	Near Future	Codified	**0**	Method	Strategist
Interviews	-	Yeah. ++There has been a LOT of PEOPLE COMING IN AND COMING OUT for the up-start meeting.	Transcript	-	-	**0**	Implicit Social	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Interviews	-	And I have been talking about these routine meetings with POWER and PARTNERSHIP management which is very important part of knowledge management, I would say because we have to know what's going on, what's coming and what's going to be installed in the production units for green electricity and things like that.	Transcript	-	-	Core capability utilisation	Implicit Social	De-centralised	**0**	Future / Goals	Internal Specialist	**0**	Near Future	**0**	Normative	Method	Initiator

Finally, the analysis of the four datasets was done in two waves: first, patterns and

differences within each data-set were analyzed separately and in the second wave, they were

brought together by searching for patterns and differences across all four datasets. In both

waves, patterns were elicited through identifying co-occurrences of codes in data-segments.

For the within-set analysis that was done on the longitudinal data-set from the observations, a

time-sequence analysis of the codes was furthermore done in order to identify the emergence

of patterns over time. This was only possible in this dataset as it was the only one with a

distinct timeline. Finally, the identified patterns were explaining by going back to the data

segments in which they occur, and for the observations by going all the way back to the field-

notes (see Table 17) . From these analyses, specific foci and data-sets were pulled out for

each paper. For paper 3, the dataset was limited to the workshops and the interviews as well

as to the first part of the coding scheme related to "knowledge". For paper 4, all data-sets and

all codes were used. For more details and coded examples, please refer to Papers no. 3 and 4,

and for the definitions of the codes see Appendix 5.

Table 17: Overview of analysis undertaken for Descriptive Study I

Analysis Undertaken	Dataset(s) used	Purpose	Used in
KJ analysis (sorting and grouping) across initial datasets	Semi-structured interviews (limited to 5), workshop 1, initial observations	Elicit decision-making themes	Paper 2 Paper 5
Within-set analysis for confirmation of codes and sub-codes from theory	Observations of the innovation centre, across all six projects, workshop 1, workshop 2, semi-structured interviews	Coding-scheme construction	Paper 3-4 Introduction
Within-set analysis for new codes and sub-codes	Observations of the innovation centre, across all six projects, workshop 1, workshop 2, semi-structured interviews	Coding-scheme construction	Paper 3-4 Introduction
Within-set analysis of patterns and differences between sub-codes and groups of sub-codes in all codes	Observations of the innovation centre, across all six projects, workshop 1, workshop 2, semi-structured interviews	Search for larger themes in each dataset	Paper 3-4
Cross-set analysis for patterns in co-occurrence of sub-codes within knowledge	Workshop 1, workshop 2, semi-structured interviews	Search for patterns and differences	Paper 3
Within-set analysis for temporal changes in sub-codes from all codes over 13 quarters	Observations of the innovation centre, across all six projects	Search for patterns and differences over time	Paper 4
Within-set inquiry into the raw data for identifying explanations of patterns and differences	Observations of the innovation centre, across all six projects, workshop 1, workshop 2, semi-structured interviews	Explain patterns and differences	Paper 2-4

3.4 Prescriptive study (Appendix 1 and Paper no. 5)

The aim of the prescriptive study was defined through the findings from the descriptive study I, and was to create a method for supporting multidisciplinary design teams, through addressing the issue of integrating knowledge from various rapidly changing knowledge domains, facilitate the transition between exploration and exploitation, and create a common understanding between actors from the various domains working together. Although a wealth of scientific methods and guidelines existed for supporting the descriptive studies, the prescriptive phase was found to be less supported by a body of methods. This situation makes sense, considering the discussion about the different approaches to problem solving between engineering designers and scientists. The prescriptive phase is essentially a synthesis phase, and methodological support from management science is thus absent. Also, no specific methodological support was found from the design research community because the synthesis method used here normally pertain to the design of products, services and systems, not synthesis of scientifically based support methods. Therefore, an approach based on product development methodology was applied for this step. More specifically, participatory design was used because Paper no. 1 found that this approach was likely to support the implementation of the methods created.

In the first phase, the analysis results were discussed with key stakeholders in the innovation center. Through these discussions, a project team was formed with the goal of creating a serious simulation game as a support method. An early version of a LEGO-based trading game was identified in the company. This game provided an ideal starting point: a project champion was automatically in place, and the platform was flexible enough for us to create the method without being constrained by the platform because the trading game had never been finished. In the next development phase, a total of six iterations were conducted, where prototypes of the game were tested with between six and eight users in each iteration. Finally,

when Ensight was finished, a facilitator course and debriefing tools were created to support the dissemination. In total, Ensight was played with more than 100 people internally in the company and 70 people outside the company. For more details on Ensight, see Appendix 1 and Paper no. 5.

3.5   Descriptive Study II (Paper no. 5)

The last step in the DRM is a descriptive study with the purpose of evaluating the support method developed. If the prescription developed in the project is of an initial nature, e.g., a set of initial guidelines, a formal validation is less important because the proposed method is close to the actual analysis conducted; few or no assumptions have been made. However, in this study, a comprehensive prescription was made in the form of Ensight; thus, a rigorous validation is required because of the assumptions that have inevitably been made during synthesis. In this study, tests were formulated for construct validity, internal validity, and external validity (see Table 18). Construct validity control was done by having key informants review the constructs at several different levels of the study; both the models constructed from the descriptive study I and the final Ensight game were evaluated by more than three stakeholders from the innovation center. Internal validity was tested through structured interviews with 35 interviewees from the company who had been playing the game and who were interviewed between 2 and 12 weeks after the game to allow for reflection and behavior change to have taken effect. The interviews were based on an extended version of (Kirkpatrick, 1978) found in (Ahmed & Wallace, 2004), and boundary object theory. The external validity was tested through a controlled experiment with students at DTU and Stanford University performing a standardized design task before and after playing the game. These tasks were evaluated against the success criteria defined during research clarification. For more details, see Paper no. 5.

Table 18: Overview of analysis undertaken for Descriptive Study I

Analysis Undertaken	Dataset(s) used	Purpose	Used in
Participatory test with knowledgeable individuals (6 iterations carried out)	12 Energy network members 12 Innovation developers (DE) 40+ R&D employees (DE)	Test construct validity	Prescription
Paired ANOVA, single factor with two levels	Multidimensional quality-ranking of 37 concepts generated in experiments with students	Elicit in which quality-dimensions significant change due to prescription is observed (External validity)	Paper 5
Spider-web analysis on 10 dimensions identified through the earlier KJ analysis	Multidimensional quality-ranking of 37 concepts generated in experiments with students	Visualize changes across all quality-dimensions (External validity)	Paper 5
Descriptive statistical analysis of established indicators for evaluating prescriptions	35 Structured interviews in industry, utilizing 7 point scales for rating of Ensight.	Analyze of effects of prescription within the case it was created. (Internal validity)	Paper 5

4 Summary and discussion of contributions

This chapter provides an overview of the five research Papers in which this study has been reported. The Papers are presented chronologically; thus, they show an increasing clarity and maturation of the research, in addition to reporting concrete results (see Table 19 - Table 23). The overview provides the background for understanding the subsequent discussion across the Papers. For full detail, please refer to the original Papers.

Paper 1: The development and use of procedures for supporting design activities was investigated. The study found a variety of implicit procedures affecting the design activities at least as much as the process management models. The main conclusion was that a user-centric approach for developing design support should be adopted to mitigate the identified challenges and utilize the opportunities in eliciting knowledge from implicit procedures, for example. With this process in mind, the next study at DONG Energy was arranged, and the findings from Paper no. 1 were confirmed to be valid at DONG Energy as well.

Paper 2: In this study, an exploratory approach was used to further clarify the aims of the research and ten specific domains of knowledge were identified as the focus.

Paper 3: The challenges of managing knowledge within the ten domains identified in Paper no. 2 were examined using a three-phase model that describes the front end, the product development and the transition phases between the two in detail. The model was examined with the purpose of understanding the exact nature of the challenges in this specific case. From this insight, the outward indications of an inherently messy innovation process led to the study presented in Paper no. 4.

Paper 4: The innovation centre and its projects were studied for more than three years. The primary conclusion from this study was an explanation of how four classes of dynamic

capabilities for balancing exploration and exploitation in innovation evolve over time, and how design teams contribute to this evolution. Another aspect of this finding was the insight into how the innovation process may be supported by affecting three categories of activities: those related to knowledge, decisions and foresight, all of which the dynamic capabilities were seen to affect.

Paper 5: Quantitative research was adopted to test a support tool, developed on the basis of insights from the previous papers and from boundary object theory. The method was tested at DONG Energy and in an experimental setting. From this study, it was concluded that the support improves the quality of the design concepts, that boundary a object is a strong tool for innovation support and that embedding support mechanisms and information into a game is an effective approach to span boundaries in cross-disciplinary teams. Thereby, it enables design –teams in developing dynamic capabilities, through filling out a role as dynamic knowledge integrator in the knowledge management infrastructure.
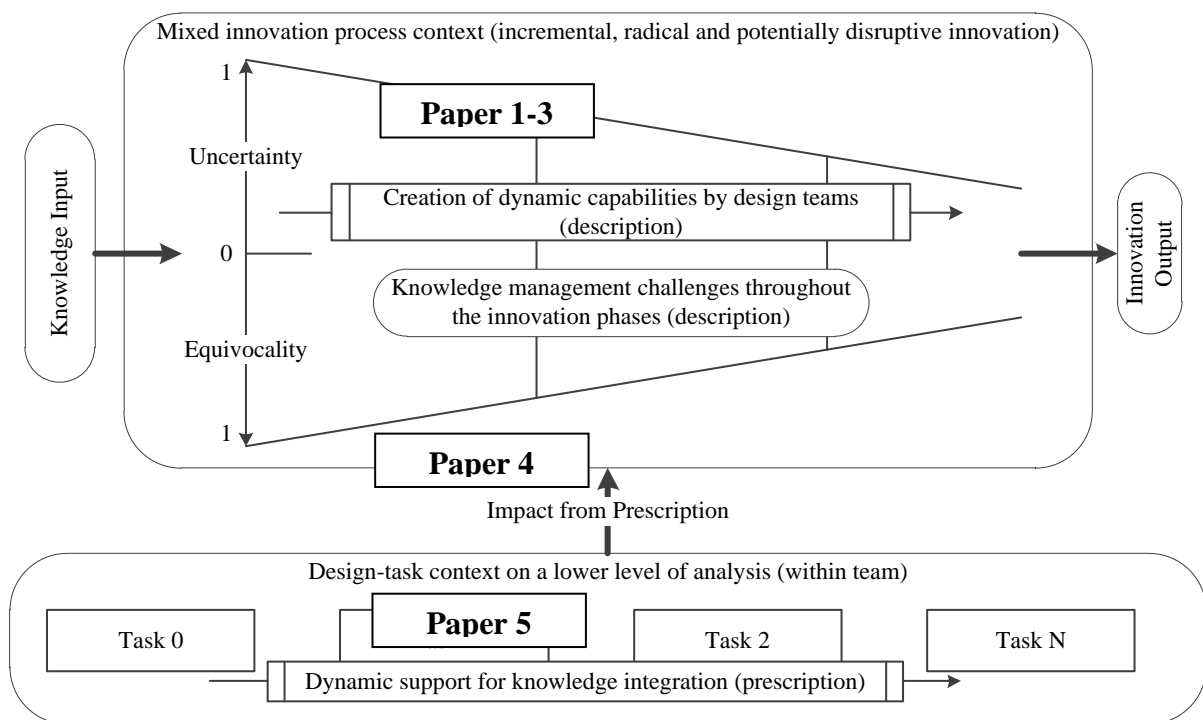
Figure 7: Position of each paper on the phenomenological overview

Table 19: Overview of Paper no. 1

Title	**Acceptance and divergence from engineering design procedures implicating knowledge flow**
Publication	Conference Paper in ASME IDETC/CIE 2009, San Diego (Published)
Research Question	Why are the established design-procedures not used the way they are intended, and how can design-procedures be turned into a widely accepted supportive tool for transferring critical knowledge between the design engineers and service engineers?
Theoretical Background	- Product development processes - Engineering knowledge management - Content motivation theory
Approach	- Cross-sectional study - Single-case study - Thematic coding analysis, iterating between data and theory
Empirical data	- 20 interviews with equipment designers procedure developers - Aker solutions (Norwegian oil drilling equipment company)
Findings	The findings suggest that a complex understanding of procedures and reasons for divergence needs to be adopted, where implicit as well as explicit procedures are recognised and managed. Three distinct types of implicit procedures were uncovered through the study: 1) historical implicit procedures; 2) social interpretations of explicit procedures and; 3) implicit procedures supporting needs that are not catered for by the explicit procedures. In this understanding, a procedure can be any kind of method, tool or framework used to support design engineers. The three factors of highest importance to motivate the use of procedures were found to be: t*ask significance, feedback* and *social recognition*. From this group, it is noted that the first factor, *task significance* scores more than twice as high as the others. This finding states that the highest motivational factor is the ability to see the direct effect of using the procedure; either on one's own work, or that of your peers.
Contributions	As many of the identified issues in the Paper were found to be related to poor procedure-user understanding, the summary of the changes to be made to the procedure development process results in the development of a user-driven interessement model for concurrent procedure development and implementation, which resembles a mental image of a vortex more than the water fall that is the current image. The practical implication of understanding the implicit procedures as the three types listed above, is the ability to understand which types of procedural knowledge the procedure developers needs to elicit during their user-oriented interessement-design of methods and tools. Furthermore, this understanding enables management of both implicit and explicit procedures, which may as well be used support each other instead of competing for control.

Table 20 Overview of Paper no. 2

Title	**Informing early-phase technology decisions in paradigmatic innovation**
Publication	Conference Paper in DESIGN 2010, Dubrovnik (Published)
Research Question	How are decisions regarding technologies informed in the early phases of innovation, when dealing with paradigmatic *new to the company* knowledge?
Theoretical Background	- Technology assessment - Knowledge management
Approach	- Cross-sectional study - Single-case study with multiple embedded units of analysis - Empirically driven thematic categorisation analysis
Empirical data	- 5 interviews with innovation team members - 16 observations, 12 in the innovation centre, 4 in the projects - 1 workshop with 20 participants - Archival data from the corporate intranet for document analysis - DONG Energy (Danish energy utilities company)
Findings	The central finding in this article, is the model of the 10 knowledge domains which indicate whether a concept is likely to be approved in the critical go/no-go gate between exiting the front-end and entering the formal product development :
Contributions	The study was found to contribute in 4 specific ways: 1) Identification of a model consisting of 10 knowledge domains. The coverage of these 10 domains in the description of a concept is a strong indicator for the probability that the concept is approved for further development. 2) Organising knowledge for decision support in both IT systems and networks aimed at knowledge transfer through socialisation. 3) A starting point for a process where new constructivist foresight methods, including socio-technical co-configuration, can be developed in an industrial applicable manner. 4) Realisation of the intimate connection between new technologies and new product development methodologies is expected to ground the development of methods for continuous technology-driven process learning.

Table 21 Overview of Paper no. 3

Title	**Knowledge management challenges in innovation phases**
Publication	IEEE transactions on engineering management (in 2nd review) This paper is an extended version of a conference paper published in the proceedings from the ICED 2011 conference (see appendix)
Research Question	How do product development managers, charged with the responsibility of innovation in a large company, perceive the knowledge management challenges that they face throughout the innovation process?
Theoretical Background	- Knowledge Management - New product development and innovation process management
Approach	- Cross-sectional study - Single-case study with multiple embedded units of analysis - Thematic coding analysis, iterating between data and theory
Empirical data	- 6 interviews with innovation team members - 2 workshops with 23 and 54 participant respectively - DONG Energy (Danish energy utilities company)
Findings	The analysis indicated three primary categories of knowledge management challenges i.e. exploration of knowledge, exploitation of knowledge and barriers to knowledge transfer. Furthermore, the analysis indicated three primary categories of challenge moderators i.e. novelty of knowledge, knowledge domain, and knowledge retention strategy.The three categories of challenges were found to be present in all of the three innovation process phases (front end, transition, and product development), however, each challenge had a phase in which it was especially prevalent: exploration of knowledge was most significant in the front end, barriers to knowledge transfer was most significant during transition, and exploitation of knowledge was most significant in the product development stage. Furthermore, the challenges within each category were found to change, depending on the innovation phase. The three moderators were, as opposed to the challenges, not found to be more attached to any one phase or challenge. They were, however, affected by the innovation process phase, in the sense that moderators within each category changed as a function of the innovation process stage.
Contributions	This research has contributed to the understanding of knowledge management challenges through an empirical study of how exploitation of knowledge, exploration of knowledge and barriers to knowledge transfer relate to innovation process phases in innovation. Through this empirical understanding, the three moderating factors novelty of knowledge, knowledge domains, and knowledge retention strategy were identified and their role as moderators for knowledge management challenges described. Further, the indication that the transition phase between front end and product development is required to be treated as a separate phase in terms of creating knowledge management support is a contribution to the literature on knowledge management in innovation processes. For industry, this study creates a foundation for further development of knowledge management support tools, specifically aimed at supporting innovation. The overview of knowledge management challenges and moderators is considered to be a useful tool for managers in practice.

Table 22 Overview of Paper no. 4

Title	**Innovation in the making: A longitudinal case study of innovation teams at an energy utilities company**
Publication	Academy of management journal (submitted)
Research Question	How are capabilities for innovation created at the team level, and through which mechanisms do they support the innovation process?
Theoretical Background	- Knowledge Management and intellectual capital theory - Innovation process management - Foresighting and decision making
Approach	- Longitudinal study - Single-case study with multiple embedded units of analysis - Thematic coding analysis, iterating between data and theory
Empirical data	- 6 interviews with innovation team members - 2 workshops with 23 and 54 participant respectively - 486 hours of observational data from more than 100 people - DONG Energy (Danish energy utilities company)
Findings	Proposition 1: The innovation process has the following two characteristics: a) it follows a messy structure to the extent that process management tools that assume a linear flow will fail to provide team-level support, and b) it can be effectively supported by detaching the three primary support functions of knowledge, decision, and foresight from the innovation process management models. Proposition 2: The five central mechanisms for knowledge support are: a) exploitative process knowledge with close bonds to business units are central to continued high exploratory performance from the exploratory team; b) the creation of renaissance teams working in cycles of experimentation and integration improves the likelihood of creating concepts that are both novel and realistic; c) linking active mediation and creation of common frames of reference to exploration and exploitation is likely to improve boundary spanning between knowledge domains; d) new procedural knowledge is likely to be adopted faster if it is tied to technological innovation; and e) the exploratory and exploitative phases in the ambidextrous organization are likely to be able to be synchronized via innovation portfolio management. Proposition 3: a) Decisions taken socially on the specialist level with an equal weight on deterministic systems analysis and methodical constructivist foresight are more likely to yield informed decisions for innovation than decisions at management level based on pure analytics. b) The decisions in a) are unlikely to occur without specific tool support. Proposition 4: a) A clear picture of the point on the continuum between exploration and exploitation where an exploratory project, combined with a clear role of foresight, is likely to improve the speed at which such project can be absorbed into a business unit for exploitation. b) Methods for creating foresights and innovations for the mid-future are likely to help the disruption. c) Deliberate teaching of a foundation for understanding foresights correctly for the entire innovation team is likely to improve the speed and accuracy at which it adapts to new conditions.
Central contributions	- Identification of knowledge, decision and foresight as generic innovation support functions - Ambidextrous organizations will, over time, be forced to transfer innovations between exploratory and exploitative departments, which make synchronization a key challenge for performance. - In situations of radical uncertainty, a balance needs to be struck between social sense making and historical data analysis in order for decisions to be informed as and persuasive, but current tools doesn't support this.

Table 23 Overview of Paper no. 5

Title	**Boundary spanning in multidisciplinary design teams performing innovation tasks**
Publication	Design Studies (in 2nd review)
Research Question	How may spanning of boundaries, caused by knowledge asymmetries in multidisciplinary design teams, be supported during innovation projects?
Theoretical Background	- Design communication (boundary spanning) - Impact assessment of training programs
Approach	- Experimental implementation study - Combination of in vivo and in vitro experiments
Empirical data	- 34 interview respondents (employees from DONG Energy) - 22 experiment participants (students at DTU and Stanford)
Findings	The analysis indicated that the engineering designers reacted positively to the method as an aid for multidisciplinary work, learned key concepts necessary for mutual understanding across domains, had been able to change their collaboration behavior, and were producing better results in their multidisciplinary teams than they did without the boundary spanning method. The latter was confirmed across both the interviews and the experiments.
Contributions	The research has contributed to the development of a boundary spanning method for supporting multidisciplinary teams doing innovation and is based on empirical research. Three properties have been identified as key to the functional performance of the method, namely the ability to transfer knowledge by addressing syntactic barriers, the ability to translate knowledge by addressing semantic barriers, and the ability to allow joint transformation of knowledge by addressing the pragmatic barrier. A central property in the structure of the boundary object has been identified in the separation between elements holding static knowledge, and levels of dynamic knowledge. This enables economy of scale in knowledge sharing in combination with flexibility towards changes in dynamic knowledge. The boundary object method developed in this study provides support for multidisciplinary teams in companies, by supporting collaboration in team compositions with higher levels of diversity and depth of knowledge, than without the method. High levels of diversity and depth has been shown to increase productivity and innovation height in design teams. The game was shown to be an effective way to teach complex subjects, such as the market mechanisms of the international energy exchange. This contribution has been introduced into a corporate educational program and the teaching at the technical University of Denmark. In both places, Ensight serves as a flexible platform, in which a plethora of different future scenarios are experienced by the participants, thus providing them with a deep understanding of the causal relations between the market and the physical elements of the energy system.

4.1 Balancing exploration and exploitation for innovation

The following section is an extension to the discussion found in Paper no. 4, in which the data for backing this discussion up is also found. From this longitudinal analysis of the innovation process, it was found that the innovation centre, in its role as exploratory unit, was moving in cycles of punctuated equilibrium (see **Error! Reference source not found.**). This finding extends current theories on ambidextrous organizations in which the assumption is that exploration and exploitation activities are placed in separate organizational units, one that re-thinks processes and products and one that focuses on incrementally improving the processes and products. The study of the engineering designers carrying out the exploration revealed that they relied on certain competencies in exploration, however, also to a large extent on competencies in exploitation.
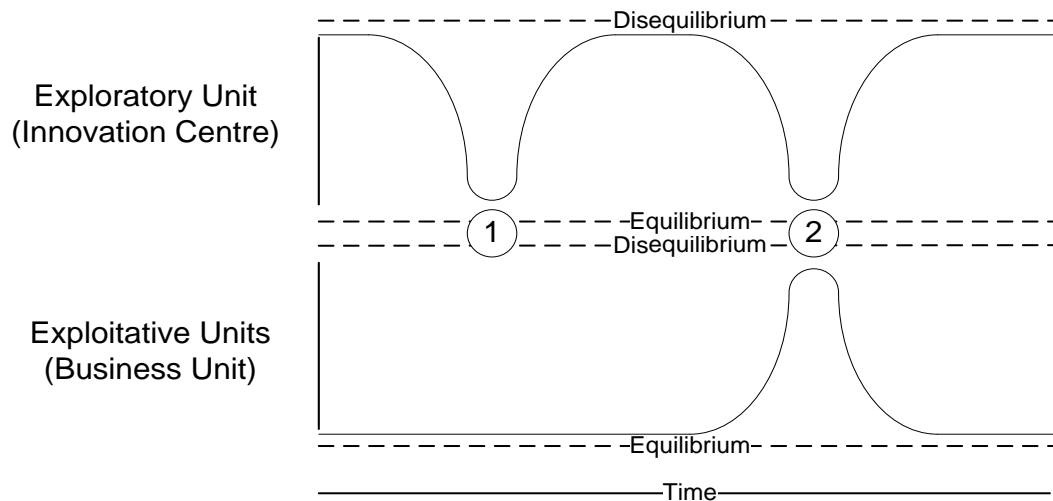
Figure 8: Synchronizing punctuated equilibrium in an ambidextrous organization

At the beginning of the study, when the innovation centre was created, an attempt to run a pure exploration strategy was made in which all processes were re-thought through support from a course for the managers involved at Stanford University. Multiple promising explorations were initiated that worked from open problem descriptions, such as whether

exploring the electrification of society could be supported through involving users in innovation and exploring for new applications of enzymes in the energy sector. However, the managers and engineers realized that some degree of support was required from the specialists in the business units because the innovation projects often required highly specialized domain knowledge. Furthermore, it was observed that a missing link to one of the business units led to the absence of exploration in that technological area. As a consequence, the engineering designers started to do more exploitative work and collaborate with the business units during periods in which the business units were open to explore new things. The cycles of punctuated equilibrium developed in this way as an emergent practice and not as a deliberate strategy. It was found, furthermore, that these cycles were supporting at least three purposes.

- First, they helped to legitimize the existence of an exploratory unit that the innovation centre proved capable of creating business on its own. The successes generated trust, which would later help the transfer of new technologies to the business units.

- Second, the waves were observed to have a practical purpose as the capacity for maturing innovations internally in the innovation center was negatively affected by the long lead times of the technologies, which necessitated a transfer to the business units. This transfer was typically conducted in a protected environment that was dedicated to maturing and exploiting the technology and not to exploratory activities.

- Third, the waves were observed to facilitate the transfer of process knowledge between the exploitative business units and the exploratory innovation center, which was enabled by frequent contact between the innovation teams on both sides. This knowledge was essential for both sides to have a common frame of reference when technologies were to be transferred.

O Reilly & Tushman (2004) describes how the role of the high-level manager is significantly more challenging in an ambidextrous organization than in a regular one because the manager must balance the contradictory activities of exploration and exploitation. The findings that in the industrial context no pure separation of exploitation and exploration is possible in the long run has implications for high-level managers and managers of operational units as they are collectively responsible for synchronizing the punctuated equilibria in the two departments and for balancing the levels of exploration and exploitation. This goal is further complicated by the finding that rigid process management models cannot be used as a tool for this synchronization as such models are counterproductive to the exploratory units' productivity, a finding further supported by (Benner & Tushman, 2003).

For the engineering design teams creating the innovations, the implications of the finding are that they are required to possess knowledge on how to do both exploration and exploitation, which is challenging as these knowledge sets are contradictory in nature. In this study, it was observed that this dilemma was solved at the team level, where a combination of exploratory and exploitative knowledge was reached through a deliberate composition of individuals. However, this approach led to an increase in the levels of conflicts, caused by contradictory opinions on use and development of processes. Furthermore, project goals, decisions, and even the definitions of the projects themselves become increasingly ambiguous, which makes the prioritization and definition of clear tasks challenging. One way to address these challenges was the introduction of a boundary object in the team that was specifically designed to integrate considerations of the context for the innovation as it looks right now with considerations of contextual changes that may be worth exploring.

4.2 Four classes of dynamic capability creation from the innovation function

In the literature review, three essential support functions for innovation processes were described: support for; knowledge, decision, and foresight activities. This model was confirmed in Paper no. 4, and a set of support propositions were developed. Each of these propositions is related to a type of dynamic capability, based on the intellectual capital view that the innovation function was found to create.

The propositions for supporting innovation are specific mechanisms in which dynamic capabilities, classified according to intellectual capital, were found to evolve and support at least one of the three innovation support functions (knowledge, decision, and foresight). An impact matrix was created as an overview with the four classes of dynamic capabilities as the independent variable, the three categories of support for innovation as the dependent variables, and the observed mechanisms as the mediators (see Table 24).

Table 24: Impact matrix showing causal mechanisms for innovation support

	Dynamic capabilities in a knowledge resource perspective: How may dynamic adaption of knowledge-resources and routines be supported			
Output type:	**Human Capital**	**Social Capital**	**Organizational Capital**	**Artifactual Capital**
Knowledge • Resources • Routines	**Proposition 2.2** the creation of renaissance teams working in cycles of experimentation and integration improves the likelihood of creating concepts that are both novel and realistic. Illustrative quote: *"001: A team with all skills needed is impossible to create when you start a project, but you can make sure a team has broad enough competencies to notice when they need another expert. "*	**Proposition 2.3** linking active mediation and creation of common frames of reference to exploration and exploitation is likely to improve boundary spanning between knowledge domains Illustrative quote: *"002: Innovation Center is characterized by project work and cross organizational collaboration, which require knowledge sharing across all barriers to deliver fast enough results to keep up with competition."*	**Proposition 2.1** Exploitative process knowledge with close bonds to business units are central to continued high exploratory performance from the exploratory team**.** Illustrative quote: *"PEDCA: S&D starts an innovation unit, spawning the discussion: should innovation drive BM's or vice versa?"*** **Proposition 1** The mixed-mode innovation process has the following two characteristics: **1.1)** it follows a messy structure to the extent that process management tools that assume a linear flow will fail to provide team-level support, and **1.2)** it can be effectively supported by detaching the three primary support functions of knowledge, decision, and foresight from the innovation process management models. Illustrative quote: *"Much confusion as to where actual projects and innovation activities are placed in the process model exists. "*	**Proposition 2.4** New procedural knowledge is likely to be adopted faster if it is tied to technological innovation. Illustrative quote: *"001: "Power" dominates knowledge-production and sets KM agenda, because they have the technical assets."* **Proposition 2.5** The exploratory and exploitative phases in the ambidextrous organization are likely to be able to be synchronized via innovation portfolio management. Illustrative quote: *"The Energy flex-house could extract knowledge on how micro-production interacts in a system."* *"Merger between mobility and energy has created a demand in DE for integrating entirely new competencies."*

(Table continued on next page)

	Dynamic capabilities in a knowledge resource perspective: How may dynamic adaption of knowledge-resources and routines be supported				
Output type:	**Human Capital**	*Output type:*	**Human Capital**	*Output type:*	
Decision • Routines	**Proposition 3.1** Decisions taken socially on the specialist level with an equal weight on deterministic systems analysis and methodical constructivist foresight are more likely to yield informed decisions for innovation than decisions at management level based on pure analytics. Illustrative quote: *"004: My decision process is based on "business as usual", even though I strongly believe that a crisis will occur.* *"MAS, which creates forecasts etc. announce that they are tired of university collaborations, because universities are behind with theory."*		**Proposition 3.2** The decisions in Proposition 3.1 are unlikely to occur without specific tool support. Illustrative quote: *"002: we need to institutionalise the story about the future energy system."* *"ELSIM should be developed to include exploration of scenarios for local solutions, such as micro wind (WAF)"*		
Foresight • Routines	**Proposition 4.3** Deliberate teaching of a foundation for understanding foresights correctly for the entire innovation team is likely to improve the speed and accuracy at which it adapts to new conditions. Illustrative quote: *"003: We develop for mega-trends, thus a central capability is holding on to projects for an extremely long time, up to 20 years. "* *"Dong Energy needs continues improvement of market simulation and technology simulation competencies (the art of the possible)"*		**Proposition 4.1** A clear picture where a project is, on the continuum between exploration and exploitation, combined with a clear role of foresight, is likely to improve the speed at which such project can be absorbed into a business unit for exploitation. Illustrative quote: *"Scenario models, once big in NESA, resurfaces in the Innovation Centre, but are largely left to MAS forecasting."* *"The "pictures of the future" (made in collaboration with Siemens) takes the shape of a commonly agreed future for energy technologies that DE was already exploring. "*	**Proposition 4.2** Methods for creating foresights and innovations for the mid-future are likely to help connecting innovations for the short and long term. Illustrative quote: *"Dong Energy needs that "the future system" exist to make decisions, which leads to establishing collaboration with J.Ø. from DTU, who's PowerLab can emulate any connected future. "* *"005: Strong scenario processes lead east DK to be ready for liberalization of the power market long before west DK"*	

4.3 Challenges and moderators in the knowledge management: An analysis of the infrastructure behind the dynamic design capabilities

The mechanisms for creation of dynamic capabilities discussed above are, as stated in the conceptual framework, highly reliant on an infrastructure for knowledge management. In the study reported in Paper 3, the challenges in running such an infrastructure for multiple types of innovation projects are analysed and in this part it is brought into the discussion on dynamic capabilities: as dynamic capabilities are organizational routines, learning and KM processes guide their development, evolution, and use (Eisenhardt & Martin, 2000). This means, that the KM challenges and moderators of KM challenges needs to be addressed in order for the dynamic capabilities to evolve to their highest possible potential.
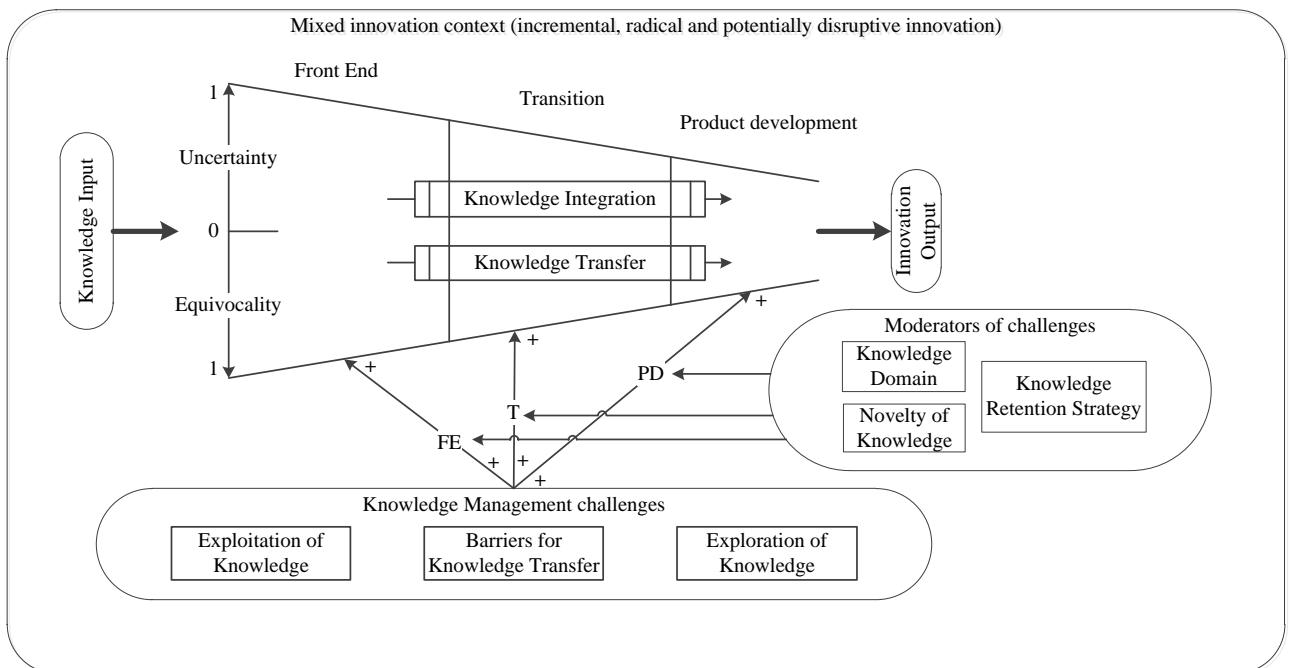
Figure 9: innovation process from the viewpoint of knowledge management challenges

In Paper 3 it was found that in order for the innovation process to bring down equivocality and uncertainty in the innovation projects, it requires different kinds of support throughout the phases. These requirements for support are further complicated by the moderators which impact all the challenges different in each phase. An overview of the central requirements, together with illustrative quotes from the data is presented in Table 25 and Table 26.

Table 25: Summary of knowledge management challenges

Front End	Transition	Product development
Challenge 1: Exploitation of Knowledge		
Collecting and combining analytical knowledge from codified sources, such as databases, was seen as a key issue in the front end, together with the extensive personal dissemination of knowledge within the perpetually changing network of stakeholders. Illustrative quotes: *"Establish "experimentarium" and persist in using courses, conferences and consultants."* *"Vital Forum: An idea-box where 2 ideas are chosen at every department meeting"*	Dissemination was found to be the central issue of exploitation in the transition phase – in the sense of "a third way" as neither personal nor codified dissemination was found to be the key issue that needed to be addressed. Illustrative quotes: *"Create some kind of common language."* *"Communication and understanding should get more attention."*	Externalizing knowledge in a form allowing for combination with existing knowledge in the company is the key issue. This finding is true for the product-related knowledge as well as for the process knowledge, as integration with an existing portfolio of products and methods is essential. Illustrative quotes: *"Develop Knowledge Database for project handbooks further, PinQ* [Electronic project management system] *etc."* *"Common document handling system for the whole company."* *"All project managers should use the same project model."* *"Make it possible to USE, not just save documents in Pondus* [data base]*"* *"Introductory course* [in document handling systems] *covering the entire organization instead of each "silo" + Follow-up course."*

(Continued on the next page)

Challenge 2: Exploration of Knowledge		
Integrating and monitoring knowledge proved to be the repeated issues, as efficient monitoring and integration of highly complex knowledge relies on specialist knowledge within the domain, which sacrifices flexibility. Illustrative quotes: *"Put us ALL in the same room and solve the assignment TOGETHER (collaborate, not just communicate)."* *"In the future - Set innovation teams with diverse competencies."* *"Innovation happens in teams, but individuals sees the Gorilla! - The Gorilla is a new concept."* *"More attention to what "others" are thinking: What are other persons playing around with, what are other companies thinking."* *"Analyze much more coherently "what is upcoming"."*	The issue of integration and reflection increases substantially in transition. Integration is essential for the hand-over to strengthen the project and avoid losing knowledge, and reflection support is essential for clarifying product and process issues. Illustrative quotes: *"The divergent thinking is easy, the convergent is hard – no one wants to de-select anything - But it creates central "non-knowledge"."* *"We go into commune with each other and agree about the actions needed."* *"Focus on the division between preject and project - it is by far not the same."*	Monitoring was found to be the most commonly repeated issue of exploration during product development because the risk calculations that are needed at this stage are still built largely on assumptions – it is a late phase, but still many creative tasks are completed which adds to the novelty of the innovation. Illustrative quotes: *"Know who are good project managers."* *"After the necessary focus on strategy, go on to focusing on the process."* *"Focus on the process and the time-perspective"*
Challenge 3: Barriers to Knowledge Transfer		
Lack of mediation and cause for interaction are the two most common issues here, and they share a common root: constantly changing areas of knowledge require active mediation to be captured and a deliberate creation of causes to interact with domains on the fringe. Illustrative quotes: *"Develop "serious games" to be used in creative workshops e.g. Association Cards, computer (simulation) games. "* *"Use of different forms of expression: Drawings, prototypes, mind-maps, metaphors; All in order to actually inspire each other."* *"Put open-minded wise and pragmatic people together + give them reason."* *"Create real rooms for innovation, open access and moderator present."*	The focus is on creating common frames of understanding during the transition phase, as the knowledge flows are now changing slow enough for this to be feasible, and most domains that get far enough to be considered for transition represent potential new innovation paths. Illustrative quotes: *"Communicate and agree on the logic behind the development of the ENERGY system."* *"Be certain of the distribution of roles before commencing work - Owner? Recipient? What are their influences?"*	Similar to the transition, in product development, the focus is primarily on creating common frames of understanding. During product development, the new knowledge is accepted as a new path, and the challenge lies in transferring procedural knowledge in particular to the executing organization. Illustrative quotes: *"Systems, hierarchy, control and goal orientation is key."* *"Management, control and system-perspective belongs together"* *"Systematics."*

Table 26: Summary of moderators of knowledge management challenges

Front End	Transition	Product Development
Challenge moderator 1: Novelty of Knowledge		
Radically new knowledge dominates the front end, and with it come all of the issues related to efficiently creating, absorbing and utilizing knowledge from completely new domains. Illustrative quotes: *"Make room for "early pirates" projects and activities - Buccaneers Aaaaarh!"* *"Wildness - Be wild enough, dream about utopias."* *"Pioneer spirit."*	During the transition phase, the main issue is that the knowledge from the front end is new to the rest of the organization – new procedural knowledge in particular can create problems because of the high inertia of existing procedural knowledge hindering transfer Illustrative quotes: *"Prejects should not end when the project starts, but run alongside and provide inputs."* *"Stop rejecting inputs and ideas from others, just because we don't understand them and are too busy to bother."*	Existing knowledge issues dominate: Unlearning of existing knowledge was found to be mainly related to procedural knowledge, and to enhance the transfer challenge. The reuse or refurbishing of still-valid existing knowledge was mainly product related and is one of the keys to sustained competitive advantage. Illustrative quotes: *"Project model - Pin Q [Electronic project management system]"* *"All project managers should use the same project model."* *"Graduate Program focused on knowledge Sharing."*
Challenge moderator 2: Knowledge Domain		
In the front end, the majority of issues are related to understanding the interplay between all knowledge domains than to any one domain in particular. This is related to the emphasis on searching out knowledge for new paths. Illustrative quotes: *"Co-create dynamic solutions in close interaction with all stakeholders. The world is changing too fast!"* *"Utilize our current assets - How to combine "airplanes" with "Grid simulations" and "European Commission reports"? "* *"Make visions by including a lot of people with a lot of knowledge - not just a hand-full of economists."*	The transition phase is dominated by understanding alliances, business models, and, to a lesser extent, the interplay between all domains. This focus is directly related to the challenge of selling into a plethora of existing business models, which is a central tool for creating a strong alliance. Illustrative quotes: *"Open mind: Don't shoot things down just because it doesn't fit into an existing frame"* *"We need to become better at getting other people interested in our ideas - Attention to the actual distribution of roles."*	During product development, the major issue pertains to the creation of a strong business model, as there is a general impatience for a proof of financial sustainability. Interestingly, there is a very low focus on technology – at this point in time, technical issues are expected to be minor obstacles not related to knowledge management. Illustrative quotes: *"Skill-upgrading of current employees in business understanding."* *"Measurement of the quality of KM methods should be coupled closely to business processes."* *"Focus on the processes, not just the product in order to repeat successes."*

(Continued on the next page)

Challenge moderator 3: Knowledge Retention Strategy		
There is a clear significance of creating knowledge internally that arises from the experience that the level of complex knowledge required in this industry is difficult to procure. Instead, researchers in promising domains were procured to do research internally in the company. Illustrative quotes: *"We are, at the moment, an oasis of nice stuff in the middle of an energy dessert - we should build from that."* *"Interdisciplinary knowledge sharing through ideation in interaction between departments or disciplines."*	Internal creation of knowledge is dominant, along with spreading and keeping the developed knowledge. During the transition phase, focus is on transferring complex knowledge through a co-creation process in which front-end people engage in joint research with the recipients for effective transfer. Illustrative quotes: *"Get a demonstration test site up and running."* *"Different compositions of groups when doing innovation from when just doing development."* *"[Create a]* Project review group." *"VITAL* [Intranet] - *Organizational plans."*	Spreading and keeping the knowledge is the key concern during product development, in which great efforts are made to educate project staff in the new technical knowledge. Internal creation is still a much repeated focus, however, and it was observed that both product and process knowledge mainly came from internal creation processes. Illustrative quotes: *"Compulsory membership in networks."* *"More elaborate text, instead of "out of context" slides (management-slide-culture)."* *"Corporate Educational Games."* *"Participants in networks should be made visible in VITAL* [Intranet].*"* *"Guide to known knowledge and Networks."*

From these tables, it is seen that the effective integration of new knowledge, which is represented as the moderator "novelty of knowledge", relies to a very large extent on bringing down equivocality between the senders and receivers, through creation of common frames of understanding and common knowledge, such as the request for skill-upgrading of all new employees in business understanding. This is a central issue in the creation of dynamic capabilities, as the design teams with their rapid shifts between exploration and exploitation has a high need for bringing new competencies on-board and in a short timespan give them a knowledge frame for understanding how they can contribute to the innovation team. This is a central dynamic capability of the design team: identification of blank knowledge domains and quick inclusion of new methodological knowhow whenever they branch into a new industry. It was seen that for the KM infrastructure to support this fast inclusion of new domains, no matter if the aim is to gain procedural or declarative knowledge, relies on the companies abilities to simulate their central value-creating

knowledge, in order for newcomers to quickly learn enough to contribute, without needing to complete several innovation projects.

4.4   Establishing and supporting the cross-disciplinary design team

The knowledge domains and competence profiles of design teams were found to affect the perception of design dimensions, i.e., the means by which functions in the concept can be achieved (see Papers no. 4 and 5). Multidisciplinary design teams, in which disciplines such as regulatory advisors and financial analysts were included as members together with engineering designers, led to an expanded view concerning which dimensions of a product can be manipulated. A product in the observed context can be designed along dimensions such as regulatory frames together with the more conventional technical dimensions – in which functionality issues are often found to have both a technical solution and a regulatory frame solution. However, these dimensions never came into play in the teams in which these unconventional competencies were not present. Furthermore, the integration between knowledge domains was determined to be a major challenge across all phases of the innovation process, and successful integration was reliant on boundary spanning (see Papers no. 3 and 5). For exploratory innovation activities, knowledge integration and creation was observed to require boundary spanning capable of handling highly dynamic knowledge and exploratory activities as well as the transition to exploitative activities (see Paper no. 4).

 Thus, the aim of Ensight (the prescription developed for this study) was to support the integration of these diverse knowledge domains while simultaneously representing knowledge domains that were typically absent from the design team. (Araujo, 2001)'s findings that new design methods are introduced via people was supported in this study as all of the process management initiatives and user-driven design methods, could be connected to individuals bringing methods in with them and spreading them throughout their networks.

However, the success of this implementation was observed to be directly connected to artifactual capital, indicating that the difference between successful implementation of the method and a failed implementation was whether the implementation was tied to the development of a concrete artifact. The apparent dependency of methods on social and artifactual capital was tested during the development of Ensight by selecting and designing the method in conjunction with a centrally placed employee, who acted as project champion, while simultaneously aiming it directly at the Etrans project, thus using the electric car technology to carry Ensight.

Through these boundary spanning functions, Ensight enables participants with backgrounds from different domains to experience how dependencies across domains will play out in the event of changes to, for example, a company's technological base, market position, innovation strategy, or regulations.
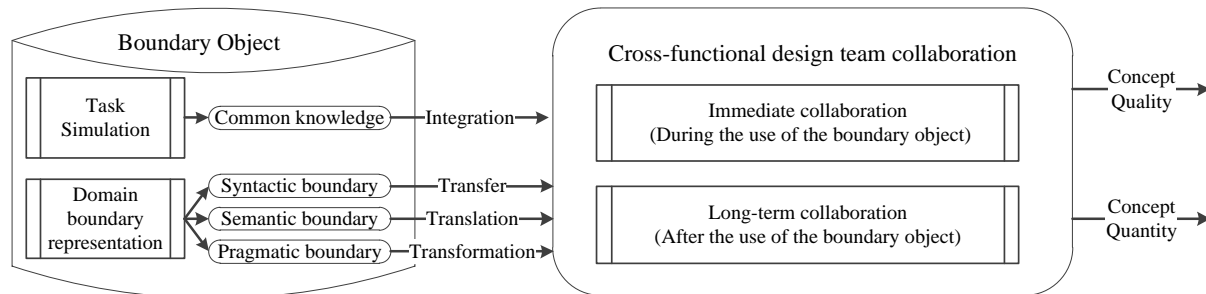
Figure 10: Observed effects of a boundary object on design team collaboration

The boundary spanning functions were embedded into the elements of Ensight's physical structure, much in the same way that functions of a product are performed by its physical structure (see Figure 10 and Table 27). The physical structure of Ensight was designed according to the design strategy described earlier by differentiating between dynamic, static and temporary static knowledge and combining elements in the game with different degrees

of flexibility towards changes. The outcome of this approach was a stable core based on knowledge unlikely to change over time but that was also flexible towards changes in any of the three boundaries to maintain the boundary spanning capabilities over time, despite changes to the boundaries caused by changes in knowledge domains.

Table 27 Characteristics of Ensight as a boundary object

Boundary	Characteristics of Ensight
Syntactic (knowledge transfer)	• In the development of Ensight, the syntax of the energy sector was incorporated into everything from scenario cards to game mechanics to allow the players to cross syntactical barriers to other domains in the sector. • The development of common syntax was further supported by extensive use of symbols and deliberate introduction of keywords, together with demonstrations allowing the participants to experience the underlying concepts of words, e.g., by physically building the '*24-hour price cross*' in Lego.
Semantic (knowledge translation)	• Through playing out scenarios together, people from different domains became aware of what 'the others' meant by specific keywords by seeing them act upon their sentences immediately. In addition, this interaction led to an understanding of how, for example, the phrase 'we need a new innovation strategy' was perceived across different levels. • On participant explained this particularly well in the following sentence: 'The most annoying thing about Ensight is that in 1½ hours, it allows the whole team to understand what it took me 15 years to learn'.
Pragmatic (knowledge transformation)	• The core of the game is built around simulating the electricity spot-market to provide a safe environment to try out new things through trial and error. Many experiments were conducted by the players, leading to a transformation of their personal knowledge. For example, one player experimented with a solution for energy storage that proved to work only if everyone acted completely rationally in the market. • Three types of knowledge stability were built into the game, through three types of knowledge repositories: (1) the rules of the game, which govern the game mechanics, represent static knowledge, e.g., the physical infrastructure; (2) the game cards represent temporary static knowledge and can be transformed when new situations arose, e.g., new legislation and technologies; and (3) dynamic knowledge was captured in the way scenarios were planned, which could be changed in minutes, and the sources of this knowledge were most often the players themselves.

In summary, the dynamic capabilities created by the design teams under the conditions of the challenges in the current knowledge management infrastructure are different in nature, but are possible to describe through the four intellectual capitals. Collectively, they require support in the form of a flexible KM infrastructure, which is detached from the conventional process management and capable of addressing equivocality more than uncertainty. This gives an indication that new elements are needed in the KM infrastructure, and the

experiment with introducing a boundary object with simulation capability was seen to effectively address a part of these requirements. In return for upgrading the KM infrastructure, dynamic capabilities will arise to strengthen and continuously adapt the operational capabilities of the design team within:

- Knowledge - dynamic integration of new knowledge, specifically in terms of industries converging and professional domains diverging, which leaves the designers to integrate as diverse domains as anthropology, European policy reports and electrical engineering.

- Decision making - in rapidly changing contexts where the uncertainty and equivocality is constantly high, the ability to adapt decision making practices rapidly based on the current context, becomes a key capability of the design team.

- Foresight – The ability to keep creating common visions as internal resources such as team-members and external conditions such as regulation change rapidly. At the same time, in situation where the lead times of projects are as high as they were in this case, the dynamic reconfiguration of vision inside project teams is a central capability.
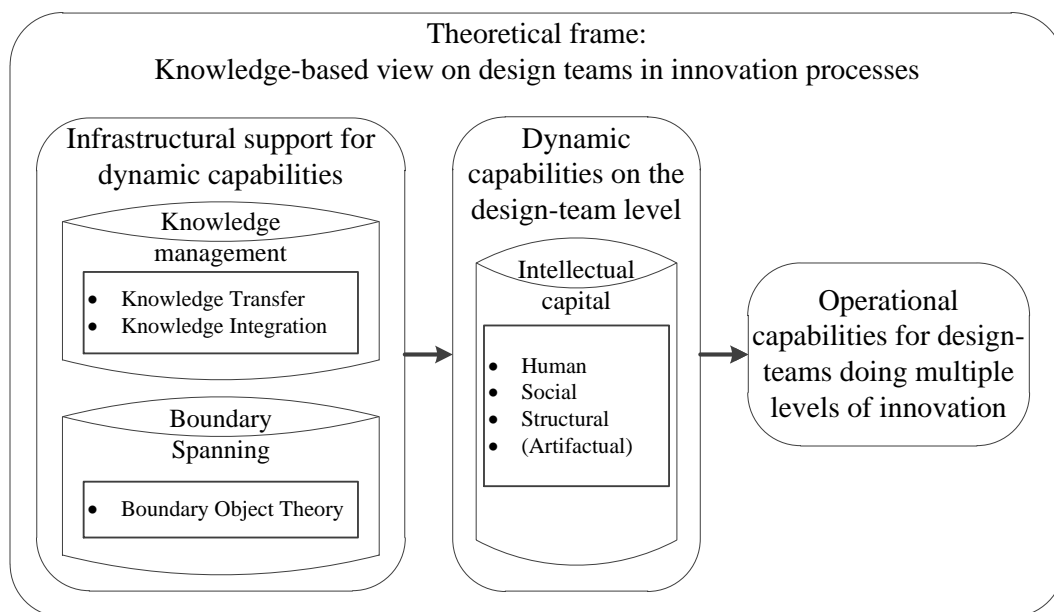
Figure 11: Conceptual frame revisited and examined in terms of contributions

5   Summary and Conclusions

This project was motivated by the challenges faced by incumbent companies in adapting to disruptive technological changes and by the identified gap in existing literature regarding the understanding of how a design team works to address the challenge of innovation and the types of concrete knowledge management tools for supporting the design of innovations. The project was performed in close collaboration with DONG Energy, which was involved throughout the entire process of the study, from the early clarification of the research goals to the experimental implementation of Ensight as demonstrator for boundary objects at the end. This case was selected as it provided a rare opportunity to study adaptation to innovation in real-time.

A study at an oil equipment manufacturer informed the approach of the primary case study, which began as a pilot study at DONG Energy to identify relevant stakeholders for the study. From the pilot study, the innovation center and six technology innovation projects were identified as the primary sources of data in a single-case study design with multiple embedded units of analysis. These sources of data were studied in depth through a cross-sectional study and a longitudinal study running over three years, employing the data collection methods of interviews, observations, and workshops. The data were analyzed through thematic coding with post-defined and pre-defined codes, with the aim of identifying challenges and support mechanisms for creating innovations. From the insights gained through these studies, the challenge of spanning boundaries between knowledge domains was directly addressed, and Ensight was developed as a demonstration tool to illustrate the effects and types of boundary objects for spanning boundaries in the design of innovations. Through implementation at DONG Energy and testing in two controlled experiments, the effectiveness of the type of boundary object Ensight represents was confirmed.

One overall research question was identified and answered through the primary case study and the controlled experiments: *How may support be provided to design teams and design managers responsible for creating disruptive technological innovation in incumbent companies?*

To answer the question, the specific knowledge management challenges in an incumbent company that performs innovation on multiple levels of innovation height were explored. Three primary challenges were determined to be central to the innovation process: exploitation of knowledge, exploration of knowledge, and barriers to knowledge transfer. Furthermore, these challenges are affected by the three identified moderators: novelty of knowledge, knowledge domains, and knowledge retention strategies. A central concern observed, was how to bridge the gap between the front-end and product development, particularly in terms of process knowledge, which combined with disruptive technological knowledge in most cases. Throughout the phases, integration of knowledge between domains was observed to remain a constant challenge, as the innovation required the integration of many domains uncommon to product development, such as regulatory frames.

The mechanisms by which multidisciplinary design teams create capabilities for innovation were then explored. Four mechanisms were proposed, by which the creation of four types of intellectual capital (human, social, organizational, and artifactual capital) were directed toward three central support functions for the innovation process (knowledge, decision and foresight). Support for the focus on integrating domains was found here, and combining the creation of a common language, a foundation for understanding and changing assumptions about the future, and detachment from the innovation process model were demonstrated to address all three innovation support functions.

In summary, issues with knowledge integration across domains and flexible methods capable of handling dynamic knowledge and the inclusion of random new knowledge domains were determined to be central for exploration activities and for the subsequent transfer to exploitation. Therefore, the prescription approach taken was the development of a boundary object specifically aimed at these issues. Thus, a demonstrator of one such boundary object was developed and evaluated in the form of the simulation game Ensight. The positive evaluation of Ensight leads to the conclusion that flexible boundary objects that focus on supporting one or more of the three central functions of innovation support are likely to be an effective support for design teams and managers responsible for creating technological innovation.

The study contributes to research on multidisciplinary design teams and to the team level of innovation management. Specific contributions from the study include:

- The project adds a real-time qualitative case study of multilevel innovation to the literature. Prior research has been almost exclusively based on historical studies, with one of the reasons being that disruptive innovation is most often realized in hindsight. By following potentially disruptive innovation in the making, a description of the coexistence of punctuated equilibrium and an ambidextrous approach to disruptive innovation was observed, which was made visible by the longitudinal observational approach. This research contributes to the debate on balancing exploration and exploitation with the proposition of real-time synchronization between organizational units, which focus primarily on either exploratory or exploitative innovation activities.

- A description of the team-level origin of dynamic capabilities for supporting innovation is proposed in the form of an impact matrix that connects intellectual capital creation with innovation process support through mechanisms empirically observed in the design teams' work. Prior research on innovation and the balancing of

exploration and exploitation has been primarily focused on the organization and industry level of theory creation, thus leaving a gap in the team level origin of dynamic capabilities. These capabilities have been determined to positively affect the exploratory innovation performance in the case company, as they replaced the role that formal process management models were playing in the exploitatively oriented departments.

- A demonstration tool (Ensight) was developed to demonstrate the effects and type of boundary objects that are likely to be effective for spanning boundaries in multidisciplinary design teams during exploration and transfer of novel innovations to the exploitatively oriented departments. The boundary object demonstration addresses the gap that while several existing studies underline that process management may not be suited for supporting exploratory activities, there is a lack of research on practically applicable alternatives for team-level support tools.

- The debate on knowledge diversity and depth in a design team as a significant driver for innovation was confirmed to also be true for disruptive innovation, with the main difference being that the asymmetries between knowledge domains are typically higher during disruptive innovation. The central contribution to this discussion lies in the demonstration of a boundary object's ability to integrate the highly diverse knowledge domains required for designing innovations on all levels of innovation height. The object was observed to be capable of addressing syntactical, semantic and pragmatic boundaries by creating a common language for sharing knowledge, a situated translation of knowledge, and by embedding dynamic, static and temporarily static knowledge, allowing for the transformation of knowledge, e.g., the basic assumptions behind technology innovations.

The project affects industry through the demonstration of a concrete tool based on boundary object theory and how it is capable of supporting the adaptation of companies to disruptive technological changes at the design-team level by easing the integration of new knowledge.

The main limitation of this study is that the descriptive study and prescriptive study were created from data that were collected from one company; thus, it is not possible to claim that the findings are statistically generalizable. However, because the theory used in the study is of a general nature and is not specific to the energy utilities domain, it is expected that the results can be reproduced and applied to other companies with characteristics similar to those of DONG Energy.

Further research in the following areas would be natural extensions to this study:

- The establishment of a quantitative study to assess the validity and importance of propositions across multiple companies to advance the understanding of the generality of the identified mechanisms.
- Precise protocol description and testing of the prescription synthesis method applied in the study. A lack of synthesis methods for the design of research-based prescriptions was observed; however, the participatory approach used in this case may be developed further through application across different cases and may enable other design researchers to be inspired and develop the method further.
- A mixed methods study in concurrent market and technology design would extend the findings of the non-technical design dimensions and potentially lead to new product models, particularly for contexts in which the regulatory dimension is essential to product development and innovation.
- Qualitative analyses in other case companies, in which organizational factors such as the complexity of products, size, age, and effect of regulatory environments are varied

between the cases, could be used to further evaluate the effects and types of boundary objects developed in this study.

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7   Contributions (Papers 1 through 5)

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ACCEPTANCE AND DIVERGENCE FROM ENGINEERING DESIGN PROCEDURES IMPLICATING KNOWLEDGE FLOW

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ABSTRACT
When developing procedures such as tools, methods and frameworks to support the development of new products, one of the challenges is ensuring their successful implementation. This paper describes a study of the development and use of such design-procedures with primary focus on the *new product development* process-model, its supporting methods and handling of knowledge. Semi-structured interviews with 20 participants have been carried out to understand the use of procedures. All the interviews were conducted in a company, which develops large complex equipment for oil rigs.

The findings suggest that a complex understanding of procedures and reasons for divergence needs to be adopted, where implicit as well as explicit procedures are recognised and managed. Three distinct types of implicit procedures were uncovered through the study: 1) historical implicit procedures; 2) social interpretations of explicit procedures and; 3) implicit procedures supporting needs that are not catered for by the explicit procedures. In this understanding, a procedure can be any kind of method, tool or framework used to support design engineers. Furthermore, the study discusses a variety of recommended actions, depending on the type of procedure and the reason for non-conformance. Recommendations for corrective actions are proposed and feedback from managers directly involved in developing and applying the procedures are collected, to evaluate them.

Keywords
Procedures; Engineering knowledge management; Design methods and tools; User driven procedure design; Process architecture; New product development

1 INTRODUCTION
Product development methods and processes are widely accepted within both engineering design research and industry. However, a survey carried out in British industry by Wright *et al.* [1] indicates that design methods are sparsely adopted or used in industrial practice. This project aim is to explore the use of procedures in an industrial product development context, with a focus on the on the *new product development* (NPD) process-model, its supporting methods and handling of knowledge. A close cooperation was established with a Norwegian oil-drilling equipment company, who kindly provided access to information, hence providing the empirical background of this project. The company had grown over a ten years period from 200 employees, to having around 1200 employees at the time of the data collection.

1.1 Background
From the literature on product development processes, the function and form of procedures are well described and therefore are not discussed here, but how procedures are defined have not been subject to the same attention. Andreasen and Hein argues that a central aspect of a good procedure is that it should make the development project quantifiable and controllable for management, thus underlining the importance of procedures, from a management perspective [2]. They define a *procedure as a model or a pattern in outline form, which can be used when working out a project plan.* In recent literature, the difference between a process and procedure becomes less distinct and Ulrich & Eppinger defines a product development process much in the same way as the above mentioned

procedure definition, whilst totally avoiding the word procedure [3].

In Coopers model of business' new product development performance, a best in class "idea to launch" framework is one of the four cornerstones [4]. With the above definition of a procedure, Coopers' framework includes procedures as one of the four cornerstones, thus underlining the effect of procedures on a company's new product development performance.

Therefore a procedure is an explicit description of how a process should be carried out, but at the same time it is acknowledged that the need of a procedure for a given process in some cases can be replaced by *mutual understanding and culture*.

From the product development theory, the development of methods and tools are very dependent on the task performed by the designer. This is of course expected as a tool generated on an abstract level has very little probability of providing for the specific context. There was also identified a gap in the literature in understanding how the procedural knowledge is created in communities [5]. From this review a need to investigate product development procedures, focusing in particular on design methods and how and why they are not adhered to was identified. Hence is the motivation for this research
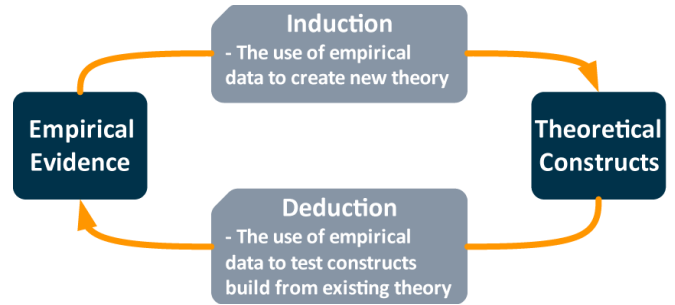
2 RESEARCH AIMS

In addition to the above literature review, the project was also motivated due to a phenomenon observed within the company, that one of the main root causes for design changes is a result of design engineers not following procedures that have been designed to support them in their work and ensure quality.

This observation led to the following specific research questions:

1) Why are the established design-procedures not used the way they are intended?

2) How can design-procedures be turned into a widely accepted supportive tool for transferring critical knowledge between the design engineers and the service engineers?

3 RESEARCH METHODOLOGY

In general, methodologies for conducting research can be divided into two approaches: 1) deductive research and; 2) inductive research. Figure 1, presented below shows the relation between theory and data for both approaches. Each approach supports the other, with the inductive using data to build theoretical constructs and the deductive approach building hypotheses or methods from theory thereafter testing them, often through comparing to empirical data, hence completing the circle.

Figure 1 - Research methodologies with respect to empirical evidence and theoretical constructs.

The selection of the most suitable research approach is dependant of the nature of the study. In general the inductive approach is well suited for relatively unexplored research areas, or areas that are in dire need of a fresh perspective. The deductive approach is, on the other hand, suited for well established research areas, where e.g. the relative importance of constructs needs to be examined [6]. The two approaches complement each other very well, as theoretical constructs build by induction is often verified by a subsequent deductive study. The choice of methodology for this study was inductive, where the empirical evidence is driving the research, and theory is taken on board as appropriate to describe the observed world. Data collection methods were selected based upon two criteria: 1) the method's ability to support the desired task [7] and; 2) the familiarity of the researcher with the method. In Table 1 an overview of the selected methods is provided, together with the reason for the choice.

Methods		
Data Collection Methods	**Capability of Method**	**Reason for Choosing the Method**
Interviews	Capturing of data	To gather empirical evidence across projects on cases
Document Analysis	Capturing of data	To understand patterns originating from the explicit procedures
Data Analysis Methods	**Capability of Method**	**Reason for Choosing the Method**
Coding	Quantitative analysis of the gathered data	To Increase objectivity in the analysis of collected data
Cohen's Kappa	Statistical test for coder reliability	To control reliability of the analysis results
KJ Analysis	Qualitative analysis of the gathered data	To systematise the analysis used to explain the quantitative findings
Sensemaking	Explanation of human behaviour	To answer the first research question
Actor Network Theory	Prescription for behavioural change	To answer the second research question

Table 1 - Overview of selected methods for this project

3.1 Data Collection Methods

Interview and subsequent transcription
The primary source of data for this study was interviews with members from the case company. In total, 20 interviews of around one hour each were collected for analysis, together with some additional topic-related interviews aimed at understanding specific details. The 20 primary interviews have been transcribed, coded and analysed. The interviewees were from three departments: equipment (design engineers), operation (service engineers) and project (design engineering managers).

Interviewees			
Interviewee No.	Function Class	Department	Procedure Relation
01	Support	Operations	Developer
02	Service	Operations	User
03	Service	Operations	User
04	Service	Operations	User
05	Service	Operations	User
06	Service	Operations	User
07	Design	Equipment	User
08	Support	Operations	Developer
09	Support	Equipment	Developer
10	Design	Equipment	User
11	Support	Project	User
12	Support	Equipment	Developer
13	Support	Equipment	Developer
14	Design	Equipment	User
15	Design	Equipment	User
16	Support	Equipment	Developer
17	Support	Equipment	Developer
18	Design	Project	User
19	Design	Equipment	User
20	Support	Equipment	Developer

Table 2 - Overview of the interviewees. *Function class* refers to the function of the interviewee in relation to the company's products, *department* to organisational setting and *procedure relation* to whether the interviewee primarily develops or uses procedures

Interviews are often classified according to how much freedom they allow for the interviewee and the type of interview used in this study was chosen to be semi-structured. This type of interview entails that a list of precise questions, referred to as the *interview guide* is prepared, and followed in each interview,

however the interviewee may expand on the answers. Also, the interviewer may probe further into interesting topics discovered during the interviews, thus it is very well suited for a study like this, where empirical findings drive the research.

Document Analysis
The secondary source of data was the written procedures accessible via the corporate intranet. Analysing these documents proved useful for understanding the historical perspective methods and procedures to be investigated.

3.2 Data Analysis Methods
The transcribed interviews were segmented into speech bursts, meaning that a new coded entity started every time the interviewee fell silent, and was asked a new question by the interviewer. Each burst was then coded according to a scheme, which was iteratively developed by searching for patterns in the interviews and relating these to theoretical models, as it is seen in Figure 2. The parts that could not be coded within the scheme were treated as topics in the subsequent KJ analysis (described later in this section), where empirical explanations on the qualitative findings were developed.
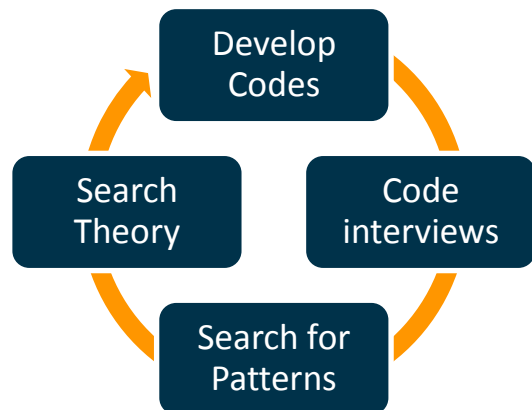
Figure 2 - The Coding Process

Coding
The coding method has been the backbone of the research, by contributing to both the quantitative and the qualitative analyses at the same time and through offering a quantitative approach to analysing the rich qualitative data gathered through the interviews [8].

Coding knowledge
From Wallace *et al.* a classification that builds on the classical definition of tacit and explicit knowledge proposed by Polanyi is seen [9]. The classification differentiates between *tacit knowledge* as being knowledge that is impossible to explicate and the user is not readily aware of it. *Implicit knowledge* that refers to the middle stage in the continuum between *tacit* and *explicit* knowledge and is defined as tacit knowledge that is possible to explicate through an eliciting process. Finally *explicit knowledge* is defined as knowledge which the holder easily is capable of explicating syntactically.

Coding Scheme		
Category	**Codes**	**Definition**
Procedure Type [7]	Tacit Implicit Explicit	How readily aware the users are of the procedures.
Knowledge Type [10] and [11]	Embrained Embodied Encultured Embedded Encoded	A taxonomy describing where the knowledge resides, and hereby how accessible it is. The knowledge types are tacit in the top, and become increasingly explicit when moving downwards.
Organisational Level [12]	Individual Group Organisation Inter-Organisation	The organisational level at which the knowledge transfer takes place.
Strategic Intent [13]	Personalization Codification	The *personalization* strategy is to get people directly in touch to share knowledge, where the opposite, the *codification* strategy, is to capture knowledge as information in databases and access it through IT systems
Motivation [12]	Skill Variety Task identity Task significance Autonomy Feedback Financial Material Social	A set of functional ways to motivate people for using a procedure, the way it is intended from the procedure designers.

Table 3- Code definitions

Coder-reliability check
As one person, coded the data from the interviews, a question about the subjectivity of the coding arises. Hence, a Cohen's Kappa test was applied to test the level of reliability in the analysis results [14]. A second coder was given a sample of the transcribed interviews to code and the level of agreement between the two coders was calculated. This was adjusted to consider the amount of agreement expected to occur by chance. *The Kappa value was calculated to be 0.5*, and this was compared to Fleiss' values of objectivity levels, being 0.4-0.6 = Fair; 0.6-0.75 = Good and 0.75 – 1.0 = Excellent. The Kappa was found to be fair; one reason for this may be the lack of familiarity with the codes for the second coder.

KJ analysis
This is a systematic approach to qualitative analysis, which is strong in combination with the coding, as it offers rich explanations on the statistical results from the coding. The KJ method is essentially a very simple model of gaining an overview of large amounts of rich data, such as user statements, interviews, observations, etc. It was originally developed for structuring data from anthropological fieldwork, and provides a bottom up approach for post-structuring of qualitative data [15], by grouping and utilising four pre-defined relationships between the groups, i.e. *Connection*, *Cause and Effect*, *Interdependence* and *Contradiction*. A series of four steps led to the overview seen later in Figure 4, which is the highest level of results being deduced from this kind of analysis i.e.

- Selection of relevant speech bursts from the transcriptions
- Grouping of the similar bursts into groups
- Merging and sorting of the groups into higher level groups
- Definition of relationships between groups, utilising the four pre determined types of relationships.

The process of sorting and establishing connections between groups of speech-burst was iterative, moving back and forth between the four steps, until a satisfactory overview was established.

3.3 Treatment of analysis results
The results were dissected through the coding and the KJ Analysis synthesised these again using the following two theoretical models: 1) *Sensemaking* [16] and [17], which was employed to understand the reasons for the missing compliance with the procedures; 2) *Actor Network Theory* [18], [19] and [20], which is strong in prescribing improved processes for development and implementation of procedures.
From *Sensemaking*, four explanatory concepts were derived: 1) *Enactment* which explains how people create the environment which impinges on them; 2) *Construed realities*, describing how in the process of enactment, people draw from a collective perception of their surrounding context. 3) *Bracketing* which describes how people build a temporary simplified cognitive model that will constitute "reality" to cope with the vast amount of information and experience that is encountered every day and 4) *Self-fulfilling prophesies*, which is in a way the result of the other three, and is best described as "thinking in circles". A *Self-fulfilling prophesy* is created when people act on their interpretations, and others notice them by interpreting them in the same way as the originator, thus verifying the self-created reality and hereby making it become true.
From the *Actor Network Theory* (ANT) the central concept derived is called *interessement* and describes the elements of a successful innovation in political terms, where the actors in the network can be of human as well as non-human nature e.g. a method or an IT system.

4 RESULTS

The quantitative and the qualitative findings, utilising the case of the corporate Product Development Model (PDM) are presented here.

4.1 Procedure Types

Through the initial analysis of the type of the procedures, it was discovered that procedures exists at least at, two levels of explicitness. The first of these is the explicit level, i.e. procedures that are officially recognised by the organisation. The second level is implicit, i.e. procedures that have emerged naturally from either social interpretation of the explicit procedures, or as solutions to unsatisfied needs. Furthermore, it was discovered that, even though these procedures are currently of equal importance, there is a clear desire in the organisation to have all procedures made explicit. These discoveries have formed the basis for the rest of the analysis, with all other factors being examined in relation to implicit/explicit procedures.

Procedure Type			
	Tacit	Implicit	Explicit
Desired	0	2	90
Actual	0	204	173

Table 4 – Desired and actual state of procedure types measured in instances.

Implicit procedure rationale

It was found that the implicit procedures existed for two separate reasons:

1. Procedures which are somewhat similar to the explicit procedures. These arise as a social interpretation of the explicit procedures and represent an operational edition, adapted to the actual world issues being faced by the users.

2. Procedures that bear no resemblance with the explicit ones and these are emergent procedures that are passed on from person to person as solutions to needs which are neglected by the explicit procedures.

Some interpretations of the procedures in category 1 differ greatly from their explicit origins, with an example being the Product Development Model (PDM), where the implicit translation is a model very similar to concurrent engineering.

The interviewees explained that they could either follow the PDM or try to reach the deadline. The PDM was perceived as utopian and not reflecting the problems of the practical development situation. e.g. the design engineers often needs to order parts before the drawings are complete due to the long lead times of large steel pieces for machining.

In reality, the design engineers were often conducting simultaneous design and production activities. When a *concurrent engineering* procedure such as this emerges naturally, it poses a risk issue for the company, as the management methods and tools cannot be applied if the explicit

procedures do not take into account the existence of such a system

From the model in Figure 3, it is seen that the ideal development process is seen as progressing in a linear fashion from concept generation to system completion.


Figure 3 - The Corporate Product Development Model

Perception of the Purpose of the Procedures
When asked directly about the purpose of the procedures, the participants' replies were quite homogenous: to ensure quality. Digging deeper into the information disclosed, not only differences in definitions of quality, but also in how the procedures were obtaining this purpose. In the Quality Assurance/Health Safety and Environment (QA/HSE) department, the procedures are seen as a tool, helping the employees, but from the employees' point of view, they are perceived as having a control function.

The perceived purpose of implicit procedures also differs greatly between the groups of interviewees. QA/HSE look at the emergence of implicit procedures as "unwanted incidents" where the design engineers look at them as emerging solutions to problems that have roots back to the procedure developers.
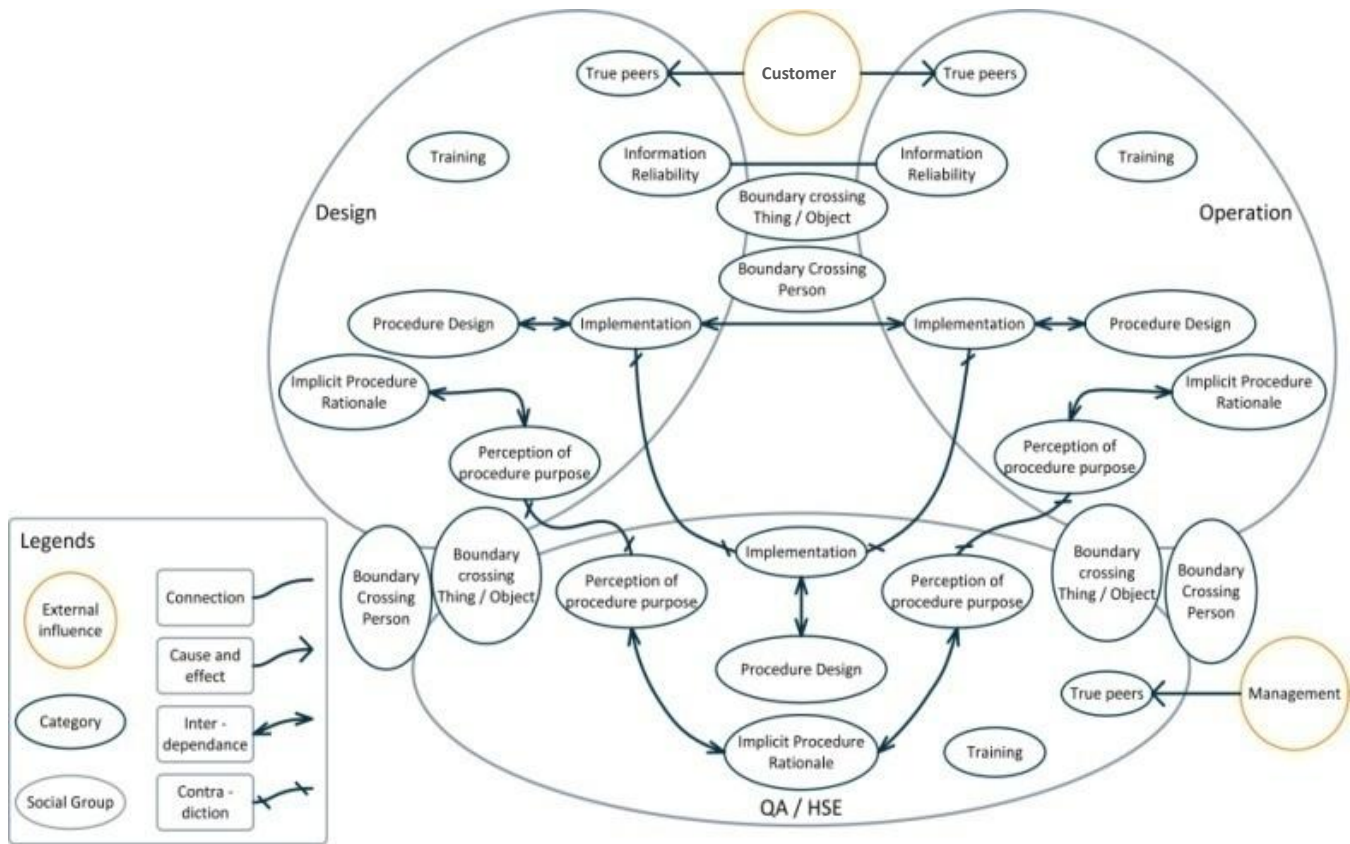
Figure 4 - Groups and relations from the KJ analysis

From the KJ analysis overview in Figure 4 there are several things worth noticing in relation to the PDM: Firstly, in the middle of the figure, it is noted how *implementation* and *procedure design* are seen as inter-dependent by all groups; while at the same time there is a clear contradiction between how the QA /HSE group, and the two other groups are perceiving implementation issues. Secondly, there is a discrepancy between how QA/HSE and the two procedure user groups, perceive the purpose of the procedures.

Part of the explanation for these differences can be found in the circles representing external influence, where the user groups perceive the customers as their true peers, while the QA/HSE perceive management as their true peers. The full explanation is, however, multi-dimensional which is discovered in the following quantitative analysis.

4.2 Knowledge Types

Table 5 summarises the differences in the procedures used depending on four distinct organisational levels [12] for which the procedure is aimed at. The taxonomy of knowledge types is based on the work of Blackler [10]

When examining Table 5 it can be noticed, starting from the right side of the table with the column showing explicit/desired, that the level "organisation" is substantially larger than the rest in all knowledge types, indicating that the observed desire of organisational knowledge management (between groups) is not confined to a few types of knowledge, but to the contrary, it is a desire related to all types of knowledge.

Embrained				
	Implicit		Explicit	
	Des.	Act.	Des.	Act.
Individual	0	5	0	2
Group	0	13	0	3
Organisation	0	9	7	3
Inter-organisation	0	3	0	0
Embodied				
	Implicit		Explicit	
	Des.	Act.	Des.	Act.
Individual	0	10	0	1
Group	0	18	0	3
Organisation	0	24	13	3
Inter-organisation	0	7	2	6
Encultured				
	Implicit		Explicit	
	Des.	Act.	Des.	Act.
Individual	1	6	2	2
Group	0	25	3	5
Organisation	0	20	17	9
Inter-organisation	0	4	3	1
Embedded				
	Implicit		Explicit	
	Des.	Act.	Des.	Act.
Individual	0	15	3	3
Group	0	36	5	12
Organisation	1	47	28	42
Inter-organisation	0	12	6	15
Encoded				
	Implicit		Explicit	
	Des.	Act.	Des.	Act.
Individual	0	11	1	1
Group	0	10	2	13
Organisation	0	19	14	61
Inter-organisation	0	6	2	23

Table 5 – Criticality of Knowledge Types with all numbers are measured in instances.
Legend: Desired State (Des.) and Actual State (Act.)

On the right-hand side of the table, another interesting discovery is made, that the explicit procedures are very focused on embedded and encoded knowledge management, but only up to group level, thereby providing virtually no support at the individual level; hence the individual members are solely managing knowledge for their own future reuse. Furthermore, it is seen, on the left-hand side that the implicit procedures takes over from the explicit when moving towards the more tacit types of knowledge as e.g. embrained, embodied and encultured. The implicit procedures are the only ones acting on the individual level, which is not entirely surprising.

4.3 Strategic intent

The knowledge types were finally examined against the strategic intent (as defined in Table 3), i.e. if a codification or personalization strategy for knowledge management was induced by the procedures. Through the analysis, it is seen that the implicit procedures support a personalization strategy and explicit procedures support a codification strategy. Moving deeper into the details, it is seen that there is close to a 50/50 split between the two desired strategies, and that this focus is solely confined to the level *organisation*. In the description of the actual state, it is noticed that the explicit procedures are significantly contributing to the personalization strategy on the level *organisation*, though the implicit procedures are still the strongest on all organisational levels of personalisation. On the contrary, the explicit procedures are by far the dominant type on the organisational levels *group, organisation* and *inter-organisation*, making a codification strategy the de-facto strategy for the procedure developers.

Personalization				
	Implicit		Explicit	
	Des.	Act.	Des.	Act.
Individual	0	9	1	2
Group	0	46	2	8
Organisation	1	58	19	24
Inter-organisation	0	23	3	10
Codification				
	Implicit		Explicit	
	Des.	Act.	Des.	Act.
Individual	0	6	1	1
Group	0	5	1	15
Organisation	0	8	22	64
Inter-organisation	0	1	2	22

Table 6 - Desired and actual state of strategic intent, related to organisational level with all numbers are measured in instances.
Legend: Desired State (Des.) and Actual State (Act.)

4.4 Motivation for Using the Procedures

A list of 8 different motivational factors was derived from Buelens *et al.*, however it was interesting to see that 75% of the analysis for motivation to use procedures can be described by three factors [12]. This picture, with the exact same factors, proved to be true in both actual and desired state. What was

even more interesting was that neither financial nor material motivation was represented in the determinant group, even though they are often promoted as key factors in consulting literature [21]. The three factors of highest importance to motivate the use of procedures were: t*ask significance, feedback* and *social*. From this group, it is worth noting that the first factor, *task significance* scores more than twice as high as the others. This finding states that the highest motivational factor is the ability to see the direct effect of using the procedure; either on one's own work, or that of your peers. Once again, the organisational level where the wish is most compelling is *organisation*, indicating that there is a general desire for motivating people to use procedures for sharing knowledge between the different groups (project groups, divisions etc.) in the organisation. The motivation must also be seen in the light of the very large differences between desired and actual situation of motivation for using explicit procedures, where the pattern suggests that there is a strong desire to increase motivation for using the procedures in general.

Motivation				
	Implicit		Explicit	
	Des.	Act.	Des.	Act.
Skill variety	0	2	0	1
Task identity	0	12	17	5
Task significance	0	41	34	16
Autonomy	0	3	1	1
Feedback	0	24	12	21
Financial	0	1	2	4
Material	0	8	10	9
Social	0	24	17	10

Table 7 - Motivational factors encouraging the use of procedures with all numbers are measured in instances.
Legend: Desired State (Des.) and Actual State (Act.)

5 DISCUSSION AND IMPLICATIONS
While analysing the coding, the results have been interpreted as providing three different types of information: 1) the category *desired* has been interpreted as representing what the interviewee *think* they want from the procedures; 2) the *implicit/actual* category is seen as representing what the interviewee actually want from the procedures and want so desperately they have already started developing them and; 3) *explicit/actual* is seen as a representation of what is supplied to the organisational members by the organisation. A perception like this closely resembles a pattern often seen in product development, where users are likely to state that they want a better version of what they already have if interviewed, but when observing them, their true needs can be discovered [3].
From this perspective, the information found in Table 4, that the organisational members want all procedures to be explicit, suggests that what the users really mean to say is that they want all types of procedures to be recognised by management, but not necessarily written down.

From the study, it is seen that the reasons for the users not complying with the design-procedures are:
- A lack of visible purpose with using the procedures, that can be observed in the near surroundings i.e. the impact on your own or your close peers' everyday work. As it was seen in Table 7, *task significance* is the single most important motivational factor for using a procedure. The challenge is that this factor is defined in the design phase of the procedure and not in a sub sequent implementation; thus, it points back to a suboptimal procedure design, with little or no understanding of the users work practice. This is further backed by the statement from the KJ analysis that *procedures are dropped on the group leaders' desk for him to implement*.
- Throughout the analysis discrepancy between the realities construed by users and developers of the procedures were seen, as evident from the KJ overview in Figure 4. There are also several coding-indicators pointing in this direction, for example the amount of implicit procedures (see Table 4), and the rationale behind the existence of them (see section 4.1) being the most clear indicators. The consequence of these competing worlds is utopian procedures, such as the PDM (see Figure 3), describing a theoretically sound solution model, but at the same time disclosing little understanding of the issues encountered in the practical world faced by the procedure users. This implication is further supported by Browning and Eppinger, who argues against the tendency of over-simplifying models of complex processes [22].
- Turning solely to the KJ analysis (see Figure 4), and the procedure developers' perspective; they are trying to increase the ownership of the procedures by making the group leaders implement them. However, from the group leaders' perspective, they are frustrated by having to implement procedures, where the rationale behind them is not understood by the leaders as the procedures are often distributed by mail, and the group leaders have very little time and motivation to search for the rationale themselves. In this process, there is no user-driven input until the end of the implementation where the procedures are audited, which mainly deals with feedback, updates and minor changes.
- Another challenge seen when comparing the KJ analysis to Table 6, is that the implicit procedures developed by the lead-users and lead-user groups [23] differ rather much in nature from the explicit procedures supplied by the procedure designers. This suggests that there is a range of unaddressed needs from the lead-users of the procedures which the formal procedure developers have failed to analyse and

support, as well as a resource for grounding demand specifications for new explicit procedures.

- Closely related to this issue, is a discrepancy between the company's knowledge management strategy, enforced through explicit procedures, being a codification strategy with strong emphasis on IT systems, and the implicit procedures, which to a large extent supports a personalization strategy (see Table 6). Surprisingly, and contrary to prior belief [12] the users wanted to share knowledge, even though this may not be supported by the formal management system.

- History matters –when observing the KJ analysis from the *sensemaking* perspective presented earlier, it is seen that the rapid increase in personnel, through the last ten years, and the existence of old networks, across departments resulted in *old procedures* is still prevailing. One interviewee had his personal set of contacts, from when he used to work in another department, which lead him to consequently bypass the explicit procedures. Others state that *there have been so many changes to the procedures, that I have given up keeping track of them all and I have been here for so long that I really don't need the procedures anymore.*

Based on this explanation a set of changes to be made on the procedural system in order to facilitate a higher degree of compliance is proposed. As the data from the study is based only on one company, these recommendations cannot be stated as several to all other companies. However, the recommendations seem likely to be true in similar company's showing similar indications as the ones observed in the analysis. This assumption will be tested in a future project.

Recommendations for change

- As there is a large non-utilised resource in the form of implicit procedures, a changed perception of implicit procedures by procedure developers, from unwanted incidents to a resource of "lead user procedures" are required. This links closely to the concepts of user-driven innovation often applied to product development and links to the QA/HSE people, who view the implicit procedures as *unwanted incidents* instead of a resource of inspiration. However, there will be a challenge in selecting appropriate observation methods for eliciting the procedural knowledge.

- The recognition of implicit procedures is also needed from the management, as dialogue about implicit procedures will facilitate a transfer of best practices. This is especially important at the individual level, as it doesn't make much sense to create explicit procedures at this level, but it makes good sense to facilitate procedural learning. One of

the key challenges here will be to control when non-constructive procedures evolve, that are not best practice; and facilitate an unlearning of those.

- To improve the motivation for using explicit procedures a clear visible purpose needs to be stated; with direct, near and short-term impact on the users' everyday work. This could be done by developing design methods that, at the same time, supports the design engineer in product development and generates reports to satisfy the gate keepers. A challenge here is to make both management and design engineers change the way they work at the same time.

- A strong understanding of which types of knowledge is critical in the organisational member's everyday work should be the foundation of a clear knowledge management strategy, which can be practically reflected in the procedures. As suggested by Hansen *et al.*, a decision about which strategy to choose must never end in a 50/50 split [13]. However this is exactly what happens when implicit and explicit procedures support different strategies.

As many of the identified issues are related to poor procedure-user understanding, the summary of the changes to be made results in the development of a user-driven interessement model for concurrent procedure development and implementation, which resembles a mental image of a vortex more than the water fall that is the current image [18].

This model, which is inspired by the ANT interessement model, should obtain its content from an in-depth analysis of the procedure designers and be a form of cooperative development, or the problems with poor implementation seen in this study will reproduce themselves.

There is, however, a discrepancy inherent in the two theories *Sensemaking* and *ANT*, which has been used to answer the questions in a sensible way. *Sensemaking* suggests that the implementation of procedures needs to be as revolutionary as possible, in order to break old construed realities, like the historic implicit procedures. On the contrary, *ANT* suggests that a slow evolutionary transition, where the new procedure co-exists with the old, is taken until the new procedure is able to stand alone. The pragmatic conclusion on this discrepancy will be that for each case of procedure development, being radical or incremental, the appropriate mix of evolution and revolution must be decided, based on the context.

6 CONCLUSIONS

The main conclusion to be drawn from this study is the importance of applying a user-oriented development procedure to the corporate groups that deals with procedure development. It seems like a paradox, that a departments who specialises in developing and implementing procedures, do not have a formal governance system for procedure innovation themselves. The results, even though they are derived from a study within only one company, are anticipated to be true in many companies as

long as they are within a similar industrial context, and exhibit somewhat similar symptoms to the ones described in the analysis.

Another result from this research project is the deeper understanding about how procedural knowledge is created in communities by series of social translations through the organisational layers, starting at multiple levels, gradually becoming more and more contextualised and accepted in the organisation while spreading at the operational level. The understanding of procedures as *explicit*, and *implicit*, suggests a continuum of procedures, ranging from tacit to explicit, where further protocol analysis could be used for discovering more details about the very tacit end of the continuum, which could not be observed with the methods used in this study.

In regards to understanding the implicit procedures, three important types of rationale behind their emergence were discovered: 1) Social interpretations of explicit procedures; 2) emergent procedures as reaction to unsupported needs and; 3) historical procedures (or, old procedures still prevailing), which represent mental brackets that have never been broken.

The practical implication of this understanding is the ability to understand which types of procedural knowledge the procedure developers needs to elicit during their user-oriented interessement-design of methods and tools. Furthermore, this understanding enables management of both implicit and explicit procedures, which may as well be used support each other instead of competing for control. A further contribution to the development of procedures is the discovery of the possible improvement in implementation performance that lies in designing procedures with this approach, where a strong sense of ownership of the procedure through co-development is obtained, as well as a higher probability for expedience towards real needs.

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DESIGN 2010

INFORMING EARLY-PHASE TECHNOLOGY DECISIONS IN PARADIGMATIC INNOVATION

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Keywords: Decision making, paradigmatic innovation, Engineering Knowledge Management

1. Introduction

The innovation activities of a company facing paradigmatic change with regard to both technology and business model includes taking many decisions, where the information available, as well as the decision makers' ability to understand this information, is limited.

Technology decisions in the very early phases of innovation have been explored in a Scandinavian energy-utilities company facing exactly these paradigmatic changes. In the company there are 5500 employees, with the major footprint in Denmark. The company has activities in the full energy value-chain including: production & trade of oil & gas, production & trade of electricity and sales & distribution to end-costumers. Their agenda is to shift from 15% sustainable energy and 85% fossil energy to 85% sustainable within 25 years. At the same time, their business model has changed from *energy planning* to *business development,* thus increasing the focus on innovation drastically.

Literature on decision making e.g. [Rasmussen, et al. 1991], often describes decisions in the very early innovation phases as "intuitive" and to be governed by "gut feeling". However, when an entire industry, in this case the energy sector, is forced to change their knowledge-world in such a radical manner, they start facing problems with making efficient decisions as knowledge generated through experience is mainly useful when the future mimics the past, which is not the case for such radical changes.

Therefore, a 3 year long research project within this industry has been initiated, with the purpose of generating an extensive understanding of the decision-making process related to assessing new technologies when designing radically new products and services for the market. It is expected that this understanding will enable further development of methods to improve the provision of knowledge and information required in the early phases of technology decisions.

This article reports on the first part of this project, and provides a descriptive model for understanding the complexity in the early phase intuitive decision-making process, answering the specific research question:

How are decisions regarding technologies informed in the early phases of innovation, when dealing with paradigmatic "new to the company" knowledge fields?

To explore the question, a case study; investigating the decisions made for radical new innovations, and the knowledge needed for supporting these decisions, was carried out. The investigation is based primarily on document analysis, interviews and observations which were carried out at the collaborating company, and the results are presented in this article.

2. **Background – Informing early decisions in paradigmatic innovation**

Motivation

Many companies in the energy sector are facing a paradigmatic shift of innovation path within the coming decades as the shift from a fossil (storable) to a renewable (fluctuating) mindset becomes more and more influential. As a consequence of this, absorption of new knowledge, the continued relevancy of existing knowledge and systematic unlearning of outdated knowledge become key industrial issues.

Knowledge and Innovation

Today, a clear link between knowledge and innovation is established, where [Tidd, et al. 2009] proposes a knowledge based definition of innovation as "*Innovation is about knowledge – Creating new possibilities through combining different knowledge sets*" Furthermore, [Adams, et al. 2006] defines knowledge management as one of the key performance metrics for measuring innovation management performance. From a process perspective, innovation can thus be modelled as a series of decisions and actions, gradually creating new business from the synthesis of knowledge.

With this perspective, knowledge management becomes a central part of innovation process quality, as [Davenport, et al. 1998]argues that "*What makes knowledge valuable to organisations is ultimately the ability to make better* decisions *and* actions *taken on the basis of the knowledge*". As this analysis is about paradigmatic innovation, the consequence becomes that innovation here is a issue of deciding, acting on and synthesising new and changing knowledge.

Technology Assessment and Decision Making

The terms *intuition* and *gut feeling* [Rasmussen, et al. 1991]described in the intro often shows up when dealing with high uncertainty and early phases of innovation. These descriptions are of little assistance when trying to understand what actually goes on in these phases, but they do, describe the central place of knowledge in this process. Grants expanded OODA model, consisting of the steps: Plan, Decide, Act, Observe, Orient, Sensemaking and Repeat [Philp and Martin] adds another useful element, besides knowledge, which is the introduction of sensemaking, and hereby difference in situational images between actors. This helps to understand different interpretations of the same knowledge. Turning to *technology assessment* [Doering, et al. 2000] propose a model for the technology assessment process (TAP), see figure 1, that describes on a overall level the phases a company goes through when assessing new technology. However, going to the more operational level, it provides very little help, as descriptions such as "scoping relevant knowledge" emerges.
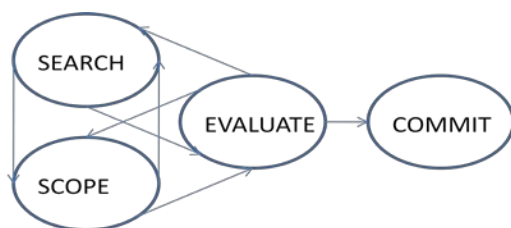
Figure 1 - The technology assessment process (TAP)

The explanation for the missing operational theory, comes when looking deeper into the theory on knowledge management e.g.[Blackler. 1995], where a myriad of classifications exist, all dependant on the context in which the analysis is to be performed, meaning it is the same case here: no meaningful hypotheses is possible to create taking origin in the context for analysis.

Research Purpose

Based on this background, the purpose of the research is to perform a case study investigation of the early-phase decisions made in paradigmatic innovation processes, with the specific research-questions to be empirically answered: *How are decisions regarding technologies informed in the early phases of innovation, when dealing with paradigmatic "new to the company" knowledge fields?*

3. Methodology

In this project, an inductive approach has been applied, where the research is driven by the case study. An approach like this is especially well suited for research in relatively unexplored areas where prior theoretical constructs are not sufficiently exhausting to get an overview of factors influencing the observed phenomenon. [EISENHARDT. 2007]

Case study Specifics

In order to investigate how decisions about new technology are informed a case study was set up with the energy utilities company described in the introduction. Data was collected from 2 different projects: Cleantech (CT) and Local Energy Production (LEP) Besides the two projects, data was collected from the corporate level Innovation-Centre (IC), due to its influence on the projects and formal responsibility for the innovation process. Most of the data collected pertain to the early phases of the company's innovation model; before the projects enter the formal corporate decision gates, see Figure 2, and form the focus of this article. In the next phase of the project, data will be collected by observing the formal decision meetings and interviewing the key stakeholders. This way the interactions between the formal and the informal decision making system will become clearer.
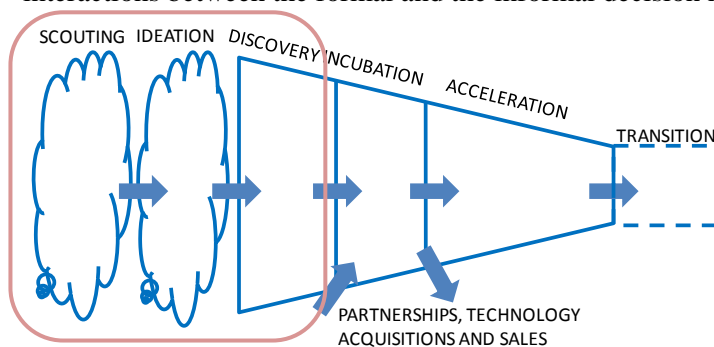
Figure 2 - Data collection focus in relation to the case-company's overall innovation model

Data Collection methods

Four different methods were applies to collect the data for the further analysis, being:

Document analysis was based on procedures, handbooks and project documentation and the major outcomes are: Understanding of project history and a description of the formal decision making system used within the company – the latter is a formal description of the right side of Figure 2.

Interviews were undertaken in a semi-structured manner, with questions in the following categories: 1) Personal Networks and their function 2) The interviewees understanding of innovation, knowledge and DM 3) Personal narratives on knowledge flow and DM 4) Experience with Methods & Tools for DM and KM. All interviews were between 1 and 1½ hour in duration, and situated in the company.

Observations were done without any predefined frame of interest, other than opportunity of observing actual technological decisions. The 4 project observations were of 1½ hour duration in average, where the 12 IC-meeting observations each took 3 hours. The latter was only recorded in field notes, as no sound recording was allowed by the company during the meetings.

Workshop was carried out with 20 people being: IC - members, project members and stakeholders with central position in the technology decision process. The workshop was a full 7 hour day, where the participants were actively engaged in creating the descriptive models from data and analysis results obtained from the interviews, observations and document analysis.

Method	Amount	Source	Data collection
Document Analysis	-	Intranet, Project Documentation	Summary notes
Interviews	5	CT and LEP Project members	Sound Recording
Observations	4+12	CT and LEP Projects, IC meetings	Sound Recording / Field Notes
Workshop	1	20 participants doing technology decisions	Produced Material

Table 1 - Overview of data collection methods.
CT = Cleantech, LEP = Local energy production and IC = Innovation Centre.

Analysis Methods

A method capable of integrating the different types of data collected with the four methods mentioned in Table 1 was needed, hence *KJ analysis* was selected due to its ability to handle different forms of qualitative data into one integrating picture, consisting of bottom-up structured elements and their relations. The KJ analysis [Buur. 1989] is essentially a very simple model of gaining an overview of large amounts of rich data. It was originally developed for structuring data from anthropological fieldwork, and provides a systematic bottom-up approach for post-structuring of qualitative data.

In the analysis, four predefined relationships were used to structure the data i.e. *Connection, Cause and effect* and *interdependence*. Besides these relationships, no other predefined structures from literature were added. After the construction of the models mentioned below, they were analysed through comparison with theory dealing with portfolio decisions – however, the objective of this article is not to prescriptive any method for portfolio management, but merely to provide a descriptive model with reflections on theory.

4. Empirical Findings

First, the formal decision making system is examined with emphasis on the early phases and radical technology decisions. Second, the case of technology decisions examined in the study is described and finally, the actual process of informing early phase decision making is described.

Formal Decision System

As in many other companies, the formal decision making model is build up around a stage-gate model, with clearly defined gates and templates for what to prepare before entering the gate. Besides the model, two committees are also part of the DM system, being the R&D committee and the investment committee. These act as high level gates, where the project needs to apply for funding as it matures. *Project idea* is the first decision in the DM model and an overview of the required information is seen in Table 2 underneath here.

Evaluation Factors	Explanation
Project Categorisation	Projects are categorised according to complexity and required investment. The higher the sum of the two factors, the more formal the project will be managed, more procedures applied and more control functions in the structure.
Budget	The requirements for amount and timing of resources
NPV	Net Present Value indicates financial value of the project
PVI	Present Value Index indicates the utilisation of the investment
Documentation Level	This measure indicates how well the project is thought through, with respect to business case, competitor analysis, risk etc.

Table 2 - Information requirements in the formal DM model

The table describes a very traditional way of evaluating projects, mainly based on financial measures. However, it became clear through both observations and interviews, that the technology decisions carried out in the observed projects did not adhere to this formal model; however, they did also get their funding through the committees. It was explained by the project managers, that the reason for not following the above model, is that it is unable to handle decisions regarding radically new technology and also is incapable of handing small start-up projects, as the supporting tools were made for calculating business cases for project on the scale of erecting a power plant.

Therefore, the next natural step in the analysis is to find out how the decisions are informed and made, when dealing with radical new technology; if, in fact, they are not following the above requirements for information as it is argued by the interviewees that they do not.

Case: Local Energy Production

To find out how the decisions were made, a case of technology decision making was studied through interviews with participants in the related projects, as well as observations of project meetings and meetings in the innovation centre where these projects were discussed. In the description, there is differentiated between *general technologies* and *specific technologies*. The difference is that the first

relates to a general range of technologies with similar function, such as "producing energy locally", whereas the latter relates to a technology for a specific product fulfilling the function e.g. heat pumps. Local Energy Production covers basically the entire portfolio of energy-producing products and related services, which can be installed in a private household. Examples of such products are geothermal heat-pumps, Small wind turbines and photo-voltaic cells. LEP is synonymous with the term *distributed generation* which is widely applied in especially American contexts.

The trend of having small scale production units in the grid has been normal on a medium scale for several years in Denmark, with the utilisation of de-central combined heat and power plants (CHP). Together with the integration of wind energy, the control and management of production from these sources has provided the company with both experience and supportive technologies to control small fluctuating units, which can be developed further to support LEP.
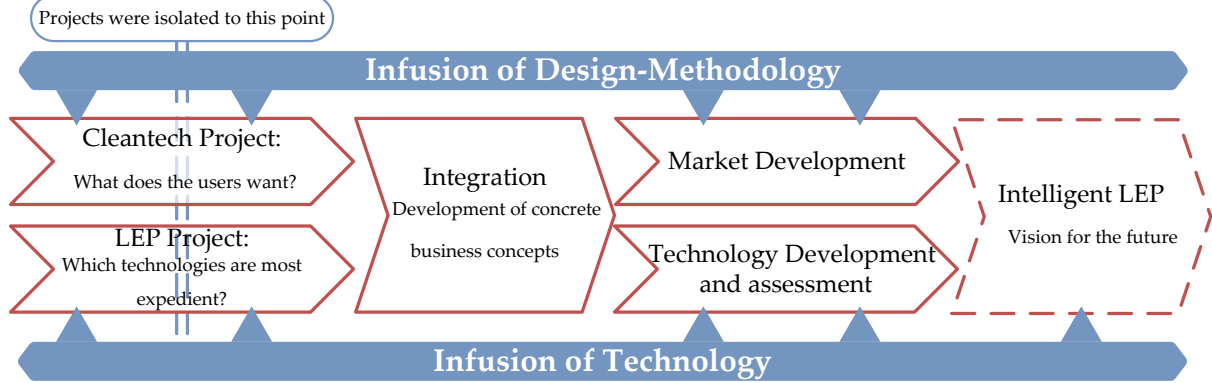
Figure 3 – Time-wise overview of central events and knowledge flows in Local Energy Production

The purpose of starting the development of LEP offerings is divided in two, as it started as two different projects in separate departments. The CT project was started after an in-depth anthropological analysis of energy customers carried out by the sales and distribution department, indicating an opportunity in the market for offering these solutions to customers.

The LEP project was the technical angle, where the purpose was to turn the potential threat posed by customers starting to produce their own electricity, into an opportunity for new business creation, by supplying a portfolio of these *specific technologies* and developing them to into supporting the needs from the grid.

The decision relating the *general technology* was made before actual projects were defined and the interviewees themselves had a hard time explaining exactly when the decision was made. From the interviews it is apparent that this decision was largely done through informal discussions internally in the company. As there seemed to be support for investigating the opportunities further, the actual projects were defined and then the further course of events is described in Figure 1. – It is interesting to note that the decision on the general LEP technology was never formalised.

As it is seen from the blue arrows of technology infusion there has basically been two rounds of decisions regarding specific technologies. In no. 1, the focus was on selecting a set of appropriate technologies to start up with. In no. 2 the focus is on assessing technologies for expanding the portfolio of products. The vision for the future of the general LEP technology is one of developing the products to enable an intelligent grid to control them, often referred to as Smart-Grid, where they will be run as small production assets on the grid.

This project was the first in the company to adopt a user driven innovation (UDI) methodology, which was a necessity due to the active role the energy user plays in a future where they own energy-production assets.

During the interviews and observations in the project teams, it was discovered that the largest portion of decisions in relation to new specific technologies, were made from intuition and that very few technologies actually made it into the team discussions. I.e. a key stakeholder in evaluating new technologies came back from a 2 day technical conference, proposing one new technology, which was discussed in the project team, before it was rejected with reference to the low maturity of the technology. However, from the conference program it was apparent that quite many technologies had been presented and yet only one had proved interesting enough to be considered further.

5

The Actual Decision Process

The observed decision process can roughly be divided into two separate phases separated in time. The first one is the intuitive and informal part. Here, the technologies show up in chaotic timing where decisions need to be made very fast. You very rarely have a well defined set of equally developed technologies to rate against each other, making attempts of selection by comparison challenging: If e.g. the technology T1 in Figure 4 is to be decided upon, DA have virtually no knowledge about how the rest of the future portfolio will look like and the existing technology portfolio is deemed as outdated due to the change in technology paradigm faced. What was seen to happen be once again the intuitive evaluation, based mainly on vision about the future, and in practice the decisions are made as quick negotiations between decision advocate and his peers. In the last part of the figure, the technologies have entered the formal DM system in the form of projects, and as it can be seen, some technologies have already been killed by the DA and his peers. In the formal system, downstream from the intuitive phase, there exist a neatly ordered process, where the technologies are evaluated based the criteria listed in back in Table 2. The reason is, that no matter how visionary the project may be, it still needs to get funding, and the way to get it is through the aforementioned committees.
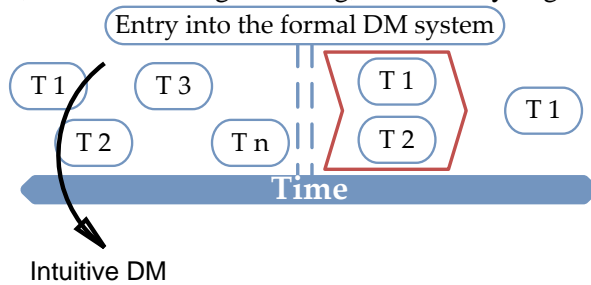
Figure 4 - The two phases observed in technological decision making

Distributed decision making describe very well the intuitive phase, where all the DA's is expected to posses the corporate DNA and hereby be equipped to make decisions about technologies, and take interesting opportunities further throughout the innovation process. When moving down stream, the decision making turns more and more central; ending with a gate where the CEO and VP's of the company is involved in all projects above a specified size. In this way, the vast majority of decisions are made distributed, but the final one is made centrally.

On the basis of a *KJ analysis* of observations and interviews; a preliminary model describing what this intuitive DM actually consists of, in terms of knowledge, was constructed. The preliminary model was then distributed at the workshop, where the 20 people were divided into 4 groups and each group was given the task of redoing the model to their liking. This process spawned 4 new models, with both extensions and reductions to the preliminary one. From these 4 models, and the extensive amount of comments posed by the workshop participants, the researchers synthesised the final model in Figure 4.
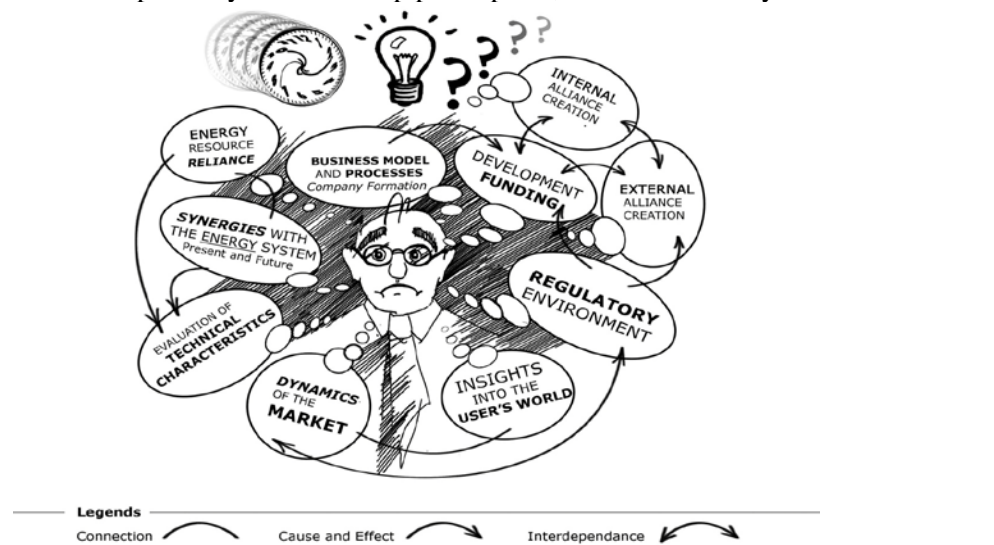
Figure 5 - Central knowledge domains for the decision advocate, and their connections

Interviewees were on average capable of supplying two or three of the domains during the interviews, however, when observing the actual decisions and having the 20 decision advocates comment on the elicited knowledge domains, the model became the detailed view seen in Figure 4. When confronted with the model, the reaction from the DA's was that they had never been readily aware that of drawing on all these domains, and therefore have not proactively tried to update knowledge in all domains.

Knowledge domains and relations

Here, the domains are explained in detail, based on a summary of the discussion from the workshop, thus definitions are strictly empirical, and can be seen as general evaluation criteria for technologies. Starting at the top *Business model and Processes* entails knowledge about *how* to develop the technology into a successful business concept. In the case described, the issue of how to do user driven innovation came in and during the workshop other procedural knowledge elements mentioned included: formation of subsidiary companies, design across large geographical distances and iterative design processes. The domain leads on to *Development Funding*, of the aforementioned business concept. Obviously, this refers to development of the technology seems likely be financed. Three main areas, shown by the *interdependence* arrows in the figure are seen to be the main sources: *Internal Alliances, External Alliances* and *Regulatory Environment*. Financing can come from one or all of the above sources and the ability to create stable supportive networks in these three spheres were described in the interviews as the primary competency of any business developer / DA. In the observed case, the decision in favour of the technology was perceived as being made, when a *signal of willingness to buy* was obtained from either an internal or external stakeholder. However, the regulatory part plays a crucial role in these decisions, by subsidising and regulating technologies. The magnitude of this effect is underlined by the presence of a *regulatory affairs* group supporting IC. A domain closely interrelated to *Regulatory Environment* is *Dynamics of the Market* which is often considered the object to be controlled by regulatory initiatives e.g. the Kyoto Protocol. Regulations are not everything though; knowledge about liberal market forces becomes increasingly important as the DA's have to argue for business cases in a market becoming increasingly liberalised. A connection on to *insights into users world* is seen, which represents another change to the sales-thinking in the company: from being mere subscribers to electricity, the electricity are increasingly gaining agency in the socio-technical system surrounding energy production, distribution and use, as was exemplified in the case description earlier. Detached from the other domains, lies the three domains making up the intrinsic technical properties of the technology: *Technical Characteristics, Synergies with the Energy System* and *Energy Resource Reliance*. The first covers the technology itself in terms such as reliance, efficiency, availability and production cost. The second covers the benefits offered when the technology is connected to others in the grid e.g. the electric cars with wind-turbines, where the storage capacity in the first can even out production fluctuation in the latter. The final domain covers knowledge about the company's dependence on resources such as coal, gas biomass and wind will be changed if developing the technology considered into a product on the market.

Early phase decision making is seen to be a highly iterative process, visiting all of the above domains, with increasingly higher quality of data as time progress. In the first iteration, where the DA is initially presented for the new technology, he will tend to use his existing knowledge in the domains. In the next iteration, the process becomes highly social and he discusses the technology in relation to these domains with his peers. It was furthermore observed that later iterations are aimed at supporting the initial decision in the form of a stable support alliance and readiness for committee funding.

Issues in Accessing Knowledge

In the following, the issues related to the DA's access to knowledge elicited through interviews and observations are presented in schematic form. However, a central notion for understanding the table is the finding that the access to the abovementioned knowledge domains relies heavily on personal interaction, as opposed to access through a system of codification.

Issue	Example from data
Issue 1: *Organisational Design* 1) Organised in four business units (BU), the company follows a classical concern structure, where each BU has its own responsibility in the	1) Project funding was described as an example of this issue, as projects with similar knowledge base were seen to be running in different BU's. This situation was caused by projects following money

value chain. However, this was reported in the interviews to create challenges regarding utilisation of knowledge across BU's who tend to focus on their own activities.	instead of knowledge. An extreme example is the LEP case described above, where no one knew that similar projects were running at the same time in two different BU's
Issue 2: *Business Processes* 1) When accessing knowledge domains in relation to a specific technology, the difference between perceived core competencies and actual/future core competencies was seen as a central issue. 2) The first iteration in the decision process is done almost without interaction thus, quality of knowledge possessed by individuals become an issue. Especially, because experience is seen to be the most dominant way of getting knowledge making *unlearning* a central theme. 3) Frequency of interaction with knowledgeable people previously unknown by the decision maker.	1) A project where the technical domain related to the project was perceived to be outside the core competencies came close to a kill, when based on a core competency developed bottom, driven by necessity in other projects. 2) In one observed case, 20 years old knowledge about user behaviour was used to make a decision about a technology's future, but this was not realised until the authors asked elaborating questions about the rationale behind the DA's negative position towards the technology. 3) It was seen that introducing a new person in a key position with entirely different competencies opened a new opportunity for the company and made the CT project possible, underlining the importance of rethinking instead maintaining the knowledge domains.
Issue 3: *Corporate Culture* 1) Personal trust is the dominant way to determine quality of information. In the first iteration through the knowledge domains, the personal trust is directed at the technology-inventor, and perception of trustworthiness decides whether to believe claims on quality of the technology. 2) Differing perceptions on how to inform a decision, caused be a merger of two opposite models, were seen to hinder the free flow of knowledge. 3) People were in general good at sharing *know what,* being knowledge pertaining to the content of a specific domain, however they are facing a challenges when it comes to sharing *know how*, being knowledge procedural knowledge.	1) In the second iteration, where the process turns highly social, the personal trust is directed towards representatives of the knowledge domains, where information almost exclusively is gathered from people already known and trusted by the DA. 2) A competition between two fundamentally different models of informing a decision was seen, caused by a merger less than 5 years ago. One model is described as *the gunslinger model* where decisions are taken as a shot from the hip, and the other one is a highly analytical scenario-model. 3) The recent shift in business model from *energy planning* to *business creation* was seen to make focus on efficient business processes very new, hence only partially adopted and any process change have to come through a concrete technological project.

Table 3 - Issues in accessing domain knowledge

5. Discussion

First, key-findings are summarised, second, these are compared to theories of technology assessment and portfolio management, and finally, the practical implications of the research is discussed together with the limitations of the study.

Summary of key findings

From the case study, three levels of descriptions is supplied: An overview of the information requirements in the formal decision making system, a description of a specific case study where technology decisions were made and finally the results from unwrapping the decision process together with participants from the company. The key findings from these activities are:

- Intuitive decisions related to the early phases in radical innovation are largely affected by downstream formal decision system, though they were intended not to be.
- Visions are made and remade all the time through discussions of new technologies, making it a whirlwind process, where new the discussions of technologies at the same time shape the

vision and are evaluated according to it in the early phases of innovation – The visions were seen to consist of anticipated future development within the 10 identified knowledge domains.

- New technologies were seen to bring with them requirements for new design methodologies, which the company needs to learn in order to benefit fully from engaging into the technology.
- Learning and unlearning knowledge within the domains were seen to happen primarily through socialisation and persistence of old knowledge a challenge.
- Examining the sources of the knowledge, it is seen to come from both external and internal sources and even though there is a shift towards more and more open innovation, the visions of the future energy system relates first and foremost to exploitation of internal knowledge.
- Definitions of core competencies was observed to be in a fluent phase, where some traditional core competencies were perceived outdated by the DA's while new competencies moved closer to the core, from mere problem solving in the past.
- Main parts of the shared vision is introduced by the wind technology, which has created a shared vision of future based on fluctuating sources, where business models can be created on the basis of supplying ancillary services to the market, through e.g. LEP.

The findings together reveal a complex socio-technical decision making system, where decisions and further development of the technology alternates; while moving in the direction of a technology vision. This vision, however, is not a solid bearing mark itself, as it undergoes changes whenever a new technology is considered. The process observed is very much in accordance with the findings from *Actor Network Theory* scholars as Madeleine Akrich, whom refers to it as a whirlwind process, where technology evolves through construction and deconstruction of stable socio-technical networks. The findings from this study add the role of socially constructed visions as bearing marks for technology development to this description.

Technology Assessment Process

In the following, the findings are considered in the view of the TAP described earlier.

The logic of the model is that there is a general body of knowledge available to the company, made up from a total sum of knowledge from internal and external sources. From this body of knowledge, the company scopes a certain part which is where they direct their attention. In the scoped part of knowledge they search and select some specific technologies represented by the geometric shapes. The scouting process will select a set of technologies, which it feeds into ideation that starts to turn the immature technologies into specific innovation ideas through a process of knowledge combination.
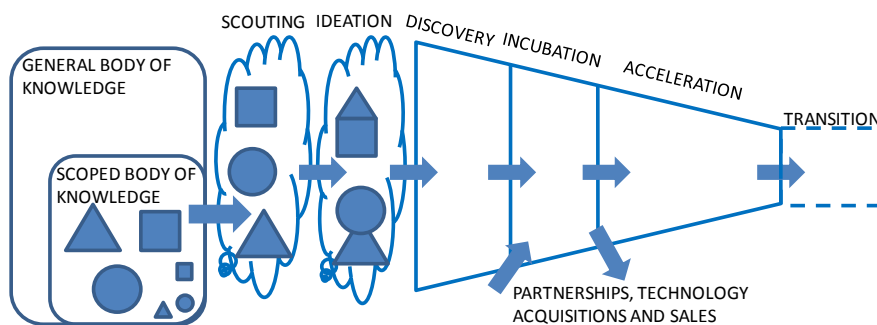
Figure 6 – Assessment of technological knowledge in the case-company's innovation model

From the first stage, where a part of the *general body of knowledge* is scoped, it is hard to be proactive in the scoping of which knowledge to actively search through, when the updating of domains mainly happens through experience. However, standing before a paradigmatic technology change force the company to look into new technology related areas, like the UDI view inherent in the LEP case. Using these new methodologies to push the boundaries of the knowledge scope could prove beneficial.

Looking at how to search through the knowledge within the scope, it seems apparent that, because the search was found to be limited by trust and personal networks and fit with the vision about the future energy system, that many potentially groundbreaking technologies will be overlooked because of their signals being too weak in this context.

Portfolio Management

Considering the function of the above assessment process, it can, in essence, be seen as portfolio management (PM) issue, where the main interest is one of the portfolios fit with a future business and technology paradigm. In the tradition of methods for this kind of fore-sighting, there is two fundamental viewpoints; a positivistic one and constructivist one. The first viewpoint is e.g. manifesting through the mathematical models for forecasting, with basis in historical data, which is much researched in fields such as Operations Management. However, the problem with applying this type of PM method in the present case is twofold: First of all, the assumption that the future will mimic the past is unlike to be true in the case of paradigmatic change. Second, even though these models are capable of handling large uncertainties in the data, they still depend on the uncertainties to actually be possible to assess, which is not the case when the technologies at hand relies on the complex socio-technical configuration described earlier.

A common way of handling this problem, is the utilisation of the constructivist scenario-technique, which was developed in the 60's by the shell corporation and since then has been refined into a quite strong strategic planning tool, e.g. for making portfolio decisions. This approach is build around mapping out a set of equally plausible futures, and then decisions are measured against their robustness across the different scenarios. A method like this would seem to be a strong way of getting the aforementioned visions about the future energy system synchronised across DA's, however, the method offers no directly operational solution to deciding in a future where value-chains are not even chains yet, but still only value-elements, tied into other networks. In conclusion, portfolio management offers no directly applicable solution to the problem; however challenges in the constructivist approach is of a nature where they perhaps could be overcome through further development of tools.

6. Conclusion, Implications and Limitations

The study is mainly based on empirical evidence, where emphasis has been putted on describing the decision making process in the early phases of innovation as it actually plays out in a real life industrial context. As such, an inherent limitation of the study is that it consists of an in-depth description in one company, hence, it is only limited possible to generalise the results to other companies. However, the study has contributes to further industrial work with developing prescriptive tools, where these results is useful along dimensions such as: 1) Organising knowledge for decision support in both IT systems and networks aimed at knowledge transfer through socialisation. 2) Further work on the elements and effect of technology-visions, on the development of new technologies within a field. 3) A starting point for a process where new constructivist foresight methods, including socio-technical co-configuration, can be developed in an industrial applicable manner. 4) Realisation of the intimate connection between new technologies and new development methodologies in the given context is expected ground the development of methods for continuous process learning.

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The challenges of managing knowledge across innovation phases

– A case study of transition to sustainable innovation in an energy utilities company

This paper aims to identify and describe the knowledge management challenges of an innovation process, consisting of multiple innovation projects. A case study of an energy utilities company, including six interviews and two workshops with a total of 83 participants, was conducted. Three categories of knowledge management challenges (exploration of knowledge, barriers for knowledge transfer, exploitation of knowledge) were identified, together with three challenge moderators (novelty of knowledge, knowledge domain, knowledge retention strategy). Challenges and moderators were found to change in nature, as a function of the phase in the innovation process, with the transition from front-end to product development found to require support for its own distinct knowledge management challenges. A central finding in this research is a descriptive model of the central changes and how the moderators affect the knowledge management challenges. Furthermore, a framework for analyzing these knowledge management challenges, which can be applied to new case studies, is also presented. This study contributes to the development of knowledge management capabilities on the level of the engineering design team for supporting innovation in industry.

Statement on managerial relevance (Required by journal)

This paper provides managers of innovation in companies with an overview of the knowledge management challenges to expect when moving from the front end of innovation towards product development. This is an empirical study within an industrial setting; hence the results reflect the challenges faced by engineering managers responsible for leading multiple innovation projects.

Specifically, it was found that innovation must be supported through a gradual shift along three central knowledge management challenges and three moderators, throughout the project. Furthermore, attention is drawn to the importance of managing knowledge specifically for transition as a separate phase, for which the major challenge lies in infusing new procedural knowledge created in the front-end into the more exploitative governance of the product development. The latter was found to be essential for ensuring replicability of successful innovation projects because it helps to integrate procedural knowledge into the existing processes of the company.

1 INTRODUCTION

Innovation management within well established companies is carried out quite systematically, where generic models of structures and processes are adapted to the specific conditions of the company. Innovation can be classified according to the outcome i.e. technologies, products, processes, business models, or any combination thereof, but also according to the extent it departs from the paths of earlier innovations (See Table 1) [1-3]. While these classifications are highly useful for analytical and predictive purposes, the situation in a company is often that innovation managers find themselves managing multiple types of innovation simultaneously. In an effort to reduce uncertainty and, to some extent equivocality changes are made to the structures and processes governing innovation [4, 5]. But, often normative innovation theory are of contradictory nature, making the adaptation to a context that combines incremental, radical, and attempts at disruptive innovation a challenging task. This paper explores the knowledge management challenges in such a context.

Table 1: Hierarchy of technological innovation types

First level	Second level	Definition
Disruptive innovation		Innovation based on technologies that bring a very different value proposition to market. These typically start with performing worse than mainstream innovations and addressing fringe customers, but end out completely changing the rules of the game.
Sustaining innovation	Radical innovation	Innovation leading to great improvements in the performance of a product, in the eyes of the users.
	Incremental innovation	Innovation leading to minor improvements in the product, in the eyes of the users.

The ability of large companies to adapt to changing environments through active participation in disruptive innovation has generated much debate in both industry and academia [6-8]. In particular, radical change in the contextual conditions of a company in such dimensions as technology, emerging markets, and regulatory frames has been shown to create challenges for otherwise well-run companies [9]. Christensen [8] found that these problems are larger for incumbent companies than for new start-ups, mainly because the processes and values of the incumbent companies are honed for efficiently sustaining an innovation trajectory, not for exploring new trajectories. The responses to these problems lie not in external stimuli, such as market regulation or governmental support schemes, but in the inner workings of the company's organizational responses [10]. Furthermore, the requirements for an organization capable of supporting disruptive innovation are very different from those for an organization capable of supporting sustaining innovation. Table 2 provides an overview of central differences between an appropriate disruptive innovation organization and that of an innovation-sustaining organization.

Table 2: Requirements of an innovation organization

Sustaining innovation [11]	Disruptive Innovation [11]	Reference
Operates within a mental framework based on a clear and accepted set of rules of the game.	No clear rules – these emerge over time, and there is a high tolerance for ambiguity.	[7, 10]
Strategies are path dependent.	Path independent, emergent strategies, probe and learn	[10]
Clear decision-making structure, often based on processes.	Emergent selection environment, based on sense making.	[10, 11]
Idea selection and resource allocation is linked to clear trajectories and criteria for fit.	Risk taking, multiple parallel bets, tolerance of (fast) failures.	[10]
Operating routines are stable and incrementally improved.	Operating patterns are emergent and fuzzy.	[10]
Impatient for growth from new innovations.	Impatient for profit from new innovations.	[11]
Strong social and organizational ties, clearly defined channels for knowledge flow.	Weak social and organizational ties and peripheral vision important.	[10]

A long-term challenge of running an innovative organization is that the appropriateness of these organizations to the their environment shifts over time, which is what Burgelman [12] referred to as punctuated equilibria – the idea that long periods of sustaining innovation are punctuated by shorter periods of disruption. Thus, a company is expected to adapt continuously to sustain innovation, and can only survive disruption if they are able to change structures and processes fast enough. An alternative solution to the punctuated equilibria is the establishment of hybrid organizations capable of doing both types of innovation simultaneously, so-called ambidextrous organizations [13]. In a company context, innovation activities and projects aiming at any or all of the types of innovations described in Table 1 are commonly carried out simultaneously. This is particularly true in ambidextrous organizations, which have structurally been set up to accommodate a broad range of innovation activities and processes [14]. Under these conditions, the task of managing the innovation organization is complicated further by the opposing requirements from the sustaining and disruptive innovation (see Table 2).

Innovation process models such as the stage-gate model are widely used for this purpose in industry and have been described by Wheelwright and Clark [15] as one of the major organizational tools to reduce the uncertainty associated with innovation. However, the equally valid concept of equivocality has been found to be insufficiently addressed in innovation management research as well as in the innovation process models applied by firms [4, 16]. Where an uncertain situation is one where there is a mismatch between the information one has and the information one needs, the equivocal situation is one where multiple and conflicting meanings exist among the innovation project participants [17]. High uncertainty as well as high equivocality is a reason for concern for innovation managers, however these are addressed in very different ways. Uncertainty is addressed through acquisition of objective information, whereas equivocality is addressed through

the exchange of subjective views with the aim of reaching a shared interpretation of the information at hand [17]. Thus, the process of innovation is generally accepted by scholars to be tightly connected with knowledge and in particular with the acquisition and efficient use of new knowledge [18-20]. Therefore, effective knowledge management (KM) practices become essential to managing the innovation performance of a company, which in turn has been shown to directly affect the long-term economic performance of a company [21]. When radical changes to the contextual conditions of a company start to occur, the need for acquisition of new knowledge increases [7]. This knowledge is often within domains that are completely new to the company [22]. Though the importance of knowledge as a central driver and barrier for a company's ability to innovate is well established [21, 23], the traditional focus from knowledge management on codifying, collecting and distributing knowledge has been shown by Berends [2] to be ineffective under the conditions of radical innovation as the uncertainty of knowledge requirements is high and knowledge often is created through experiments, with unpredictable outcome. This shows that the efficacy of a specific knowledge management approach is likely to change with the type(s) of innovation aimed at by the company,

Although much has been written about the stepwise processes of acquiring and implementing knowledge in order to address uncertainties, the dominate perspective has been "deterministic" and "mechanical", which lacks a deeper understanding of the process where information is used (or discarded) [24]. Secondly, there is a need to balance the attention put on reducing uncertainty and equivocality throughout the phases of the innovation processes in research, as equivocality has been given too little attention despite being a valid reason for deliberately discarding information. Thirdly, there is a lack of attention in literature on exploring these issues in the transition between the front end of innovation and formal (new) product development ((N)PD), which is where the central go/no-go decision is made [25].

1.1 Aims and Objectives

This paper describes the knowledge management challenges when managing incremental, radical, and disruptive innovation, through a case study in an energy-utilities company. In particular, it focuses on identifying and describing how knowledge management challenges change from the front-end of innovation through to the formal (N)PD phase at the level of product development managers and engineering designers. Thus, this paper aims to address the gap of understanding the knowledge management challenges faced by managers of engineering design teams in incumbent organizations, during the creation of innovations, how these

challenges change from the front end to the (N)PD stages of the innovation process, and to uncover the reasons behind these. The central research question addressed is:

> How do product development managers who are responsible for innovation in a large company perceive the knowledge management challenges that they face throughout the innovation process?

In the next section, a brief review of the literature is presented, focusing on the key concepts of innovation processes and knowledge management. This review is followed by the research methodology, including the coding scheme, with construct relationships presented in the Gioia model [26]. In findings, construct relationships are complemented with detailed graphs and charts in support of qualitative discussion and analysis. Finally, the conclusions are presented, and implications for practice and suggestions for future work are discussed.

2 KNOWLEDGE MANAGEMENT IN INNOVATION PROCESSES

Innovation in a corporate context is messy, which makes innovation challenging to create, let alone manage [27, 28]. Many different process models for innovation have been developed in the last 25 years – a period in which the view on innovation has changed significantly. In the early models, the view was very simple and linear, whereas the newest models are highly complex models of open networks and ecosystems [29]. Despite the contemporary view in innovation management literature that innovation processes do not progress linearly, which was assumed until the mid-1990s [28], there is still a consensus on the usefulness of linear models as conceptual models of a complex reality [27]. For the purposes of this paper, a phase model has been adopted, although it is recognized that in reality, these phases are iterative periods that often come in a chaotic succession.

2.1 Processes for innovation and new product development

Numerous studies have been conducted to identify the generic phases of the innovation process, which is also commonly referred to as the new product development process. Generally, the process is divided into three overall phases: the front end, detailed development and commercialization, with the wording changing slightly. Cooper [30] described the innovation process as consisting of three overall groups of stages with ideas starting in the predevelopment stages, move into product development and ending in commercialization. Koen [31] picked up on Cooper's [30] statement that "it is these early stages where success and failure are

largely decided" and divided the innovation process into the front end of innovation, new product development and commercialization. These phases are defined in a similar manner as Cooper's [30] phases, with Koen's [31] main contribution being an elaborated explanation and understanding of the activities within the front-end phase. Grönlund [32] reviewed the stage gate model from the emerging perspective of open innovation and defined three generic phases: define, design, and validate; in this model, focus has shifted from control of an internal process to the continuous exchange of knowledge with the company's surrounding environment, however it maintains the same central purpose of the within-phase activities as described by Koen [31] and Cooper [30]. A recent conceptualization of the innovation model divides the innovation process into front end activities and subsequently the formal new product development (NPD) process [25]. In this model, specific attention is drawn to the challenges associated with screening, refining, aligning, and legitimizing the output of the front end in order to arrive at a corroborated product definition that can enter the formal (N)PD process [25]. Thus, specific emphasis is put on the problematic transition between the front end phase and the product development phase, by focusing on the output from the front-end.

Innovation process models based on detailing the stages of these overall phases, such as the stage-gate model (also used for (N)PD), are widely used in industry and have been described by Wheelwright and Clark as one of the major organizational tools to reduce the uncertainty associated with innovation [15].

The focus of this study is how knowledge management challenges change between the first and second phases of the three-phase models. Thus, the terms *front end* and *product development* are used in the analytical frame, and specific attention is paid to the *transition* between them, as this is where the critical "go" or "no go" decision is made [25]. The final phase, *commercialization*, is outside the scope of this paper (see Figure 1). The front-end phase covers such activities as: idea generation and refinement, preliminary business analysis and project definition. The product development phase includes such activities as: detailed engineering, production planning and in-house testing. The existing literature is sparse on descriptions of the transition, except in terms of a gate between the two phases, or addressed with a focus upon portfolio management. Cooper [30] described the transition as a gate at which the cross-functional development team is approved and as the last chance of killing the project before committing into heavy financing. However, detailed descriptions of the knowledge management activities and challenges of the transition are lacking in the literature.
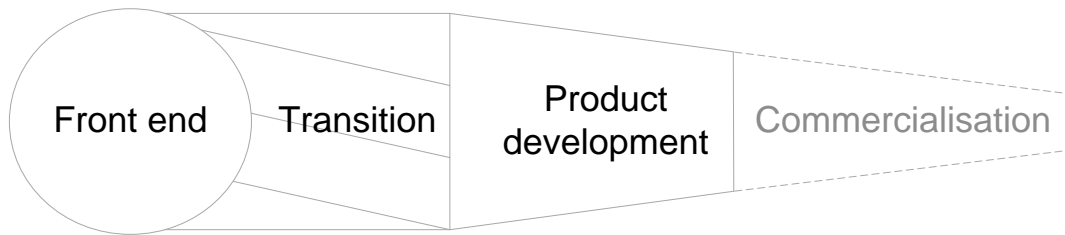
Figure 1: The major phases of the innovation process - commercialization is outside the scope of this study

It has long been recognized by scholars, such as Cooper [30] and Van de Ven [19] that the innovation process front-end is where the decisions have the highest impact on the success or failure of a product or service. Furthermore, it is significantly cheaper to change decisions in the innovation process front-end than later on, when the idea has entered the formal processes of detailed development. However, scholars and managers alike still struggle to explain and control this part of the process, whereas the (N)PD phase is better explained. Weick [33] explained that the struggle of managing exploration as caused by the long-standing historical focus on educating managers and engineers in systematic decision making. This practice is appropriate for the relatively predictable product development stages, but it is not very useful in the front-end. During the front-end phase, radical uncertainty dominates, which Tsoukas [34] defined as a lack of knowledge about the lack of knowledge. Consequently, formal decision-making tools are less applicable because they rely on an uncertainty assessment. Hence, Weick [5] suggests that innovation managers change their focus from systematic decision making to continuous sense making based on intuition and a constant flow of information and knowledge about the context of the company. During product development, knowledge plays a different but still central role: it converts uncertainty to risk. The more one know about a given phenomenon, the more one can make an informed and calculated decision about whether or not to proceed with an innovation project [27]. It is therefore expected that knowledge management in the product development phase will be very similar to strategies for sustaining innovation, whereas the knowledge management challenges in the front-end and transition phases are expected to be significantly different due to the radical uncertainty.

Within innovation process research uncertainty and radical uncertainty is, as mentioned earlier, complemented by the much less researched concept equivocality [4]. Where uncertainty can be addressed through acquisition of more objective information, equivocality can be addressed through achieving and enacting a shared interpretation of problems and solution spaces [17]. In this sense, reducing equivocality requires a higher degree of direct interaction between team members on all levels, whereas uncertainty can be addressed through

a clarification process with less social interaction. Common signs of an equivocal situation includes: Lack of clarity, extensive use of symbols and metaphors, high complexity, and existence of paradoxes [5]. In 1979, Weick [35] used the concept of the equivocality as the main reason for people to organize, later followed by Daft and Lengel [17] in 1987 who transferred the concept to information processing. However, the concept has only recently been applied systematically to innovation process research. One reason may be the dominance in existing theories of what Tucci refers to as the a "determistic" view, and Weick and Eisenhardt refers to as "mechanical" perspective, where knowledge is modeled as unambiguous, reducible and easily transferrable constructs and organizations as information processing machines [24, 33, 36]. However, with the increasing use of global collaboration and multidisciplinary teams, the issue of equivocality in innovation processes is increasingly relevant.

2.2 Knowledge-based view on innovation management challenges

The knowledge based view (KBV) of the firm has been adopted for the analysis of knowledge management challenges throughout the innovation process [36-38]. KBV is often considered an extension to the resource based view (RBV) of the firm as it maintains the view of a firm as a heterogeneous entity, where the source of sustainable competiveness is the internal resources in the firm [37]. However, KBV distinguishes itself from RBV by focusing on knowledge as the central resource of strategic differentiation rather than knowledge as one resource among many and proposes that the firms exist to create, transfer and transform knowledge into competitive advantage [39]. Knowledge is thought of as embedded into and carried through culture, processes and routines, identity, documents, IT systems, and people.

Within the KBV an evolution of the view of knowledge has taken place from viewing knowledge as unambiguous, reducible and easily transferrable constructs, to knowledge increasingly being seen as an active process of knowing. Thus, codification of knowledge is always a process of creation, as the codified knowledge can never completely replace the tacit knowledge from which it was created [36, 40, 41]. The latter view resonates well the concept of equivocality, as it permits for mutation of knowledge during transformation from one form to the other and continuous development of mental models in which the knowledge can be articulated. As a consequence of this evolution, various definitions of knowledge exists that are mainly based upon an epistemological view and the context in which the term is used [42]. As this study takes a process perspective on the creation of innovation, the active process perspective is used in combination with the classifi-

cation proposed by Wallace *et al.* [43] which is especially applicable for engineering research, as it emphasizes creation of knowledge. The classification builds on the definition of tacit and explicit knowledge proposed by Polanyi [44], thus describing tacit knowledge as knowledge that is impossible to explicate and of which the user is not readily aware. Implicit knowledge refers to the middle stage in the continuum between tacit and explicit knowledge and is defined as tacit knowledge that is possible to explicate through an eliciting process. Finally, explicit knowledge is defined as knowledge that the holder is easily capable of explicating syntactically. From the perspective of innovation processes in firms, an organization's ability to combine and integrate tacit, implicit and explicit knowledge from different domains, such as technology and market analysis, is essential to the production of new knowledge and thus the novelty of innovation [18]. At the same time, the more tacit and strategically valuable the knowledge is, the more it is expected to be a source of competitive benefit [37, 38].

Four major streams of empirical studies within KBV are: sourcing, internal transfer, external transfer and integration [36]. In order to analyze the innovation process from front-end to (N)PD, especially the internal transfer and integration streams are the most central.

Grant [37] presents a view on the company as an integrator of knowledge, based on the argument that efficient production (of e.g. innovations) requires integration of many peoples knowledge through establishing a mode of interaction where knowledge is integrated with minimal requirements for costly knowledge transfer. In order to facilitate this, four types of coordination mechanisms are proposed: rules and directives, sequencing, routines, and group problem solving and decision making. The latter of the coordination mechanisms is the only one that directly addresses equivocality and by far the most expensive; hence it is often reserved to unusual and complex cases.

These four mechanisms are all reliant on some degree of common knowledge for their operation, as the common knowledge allows individuals to integrate the parts of their respective knowledge domain that is not common. Examples of common knowledge that fulfill different roles during knowledge integration include: language, other forms of symbolic communication, commonality of specialized knowledge, shared meaning, and recognition of individual knowledge domains. In a team, this common knowledge is gradually build up through a circular process where the team performs a task, an outcome is achieved, the team explores causal relations between actions and outcomes, and common knowledge is gained [45]. The more iteration that a team undertakes this process together, the more common knowledge they gain and the more efficient they

get at integrating their respective uncommon knowledge [36, 37]. Exercises where teams solve concrete tasks related to their knowledge domains has been shown to accelerate the creating of common knowledge [46]. Even though the coordination mechanisms are essential to create efficient integration of knowledge, it has been shown that complicated rules, routines and work descriptions can increase the barriers to knowledge integration [47]. However, other studies (e.g. [48, 49]) point out that routines and rules can be used to improve knowledge integration and hence these have impact on knowledge integration although it is unclear how. The effective rules and routines seems to be the ones that allows freedom for interpretation and creative implementation, whereas the inefficient ones are the heavily rigid procedures, which quickly become obsolete and starts to hamper knowledge integration [36].

The central concepts from research into internal knowledge transfer are: the characteristics of knowledge, the sender, the recipient and their mutual relationship [36]. This is at the same time one of the central areas of knowledge management (KM): to facilitate an efficient transfer of knowledge between sender(s) and receiver(s) which could e.g. be the engineering design teams and the innovation managers or between individuals within this team.

The term "knowledge management" is rather broad and covers any systematic attempt of an organization to influence the flows of data, information and knowledge. However, Hansen *et al.* [50] provided a useful distinction between two organizational strategies for managing knowledge transfer; strategies differ based on whether their purpose is to capture knowledge in an encoded form as information or to facilitate human interaction with the purpose of direct social sharing of knowledge. The first strategy is *codification*; its focus is on transferring knowledge from into, for example, a database, thus achieving economies of scale from transforming knowledge into information with one sender and multiple receivers [51]. The second strategy is *personalization*; the focus of this strategy is on transferring knowledge from person to person via direct contact, e.g., by deliberately matching people and creating transparency in the organization. These strategies are high-level classifications for methods applied to knowledge management, but in practice, the general strategy and choice of methods to apply are dictated by the type of innovation that the company is seeking [50].

In an organization performing innovation, the methods have to support a rather challenging balancing act in which known methods for managing knowledge to sustain innovation are still needed for the product development phase but must be complemented by opposing methods in the front end. Little research has been done on the specific challenges this poses to managers, and the transition has never been studied directly. In

Table 3, an overview of currently identified knowledge management challenges based on a review by Berends [2] is shown. The lack of research on knowledge management for during the transition phase constitutes a second gap in the literature addressed by this study, represented by minuses in Table 3.

Table 3: Knowledge management challenges from the literature, gap in literature shown as "?"

Front-end	Transition	Product development	References
Knowledge exploration	Not found in literature	Knowledge Exploitation	March [7] Benner & Tushman [52]
Existing knowledge	Not found in literature	Absorbing Knowledge	Leonard-Barton [53] Cohen & Levinthal[54]
Radical Uncertainty and High equivocality	Not found in literature	Calculable Uncertainty Low equivocality	Kahneman [55] Tsoukas [34]

A central challenge for companies engaged in innovation is to balance exploratory and exploitative activities, which both compete for the scarce resources of the company. Exploration is concerned with pursuing new fields of knowledge through such activities as searching and experimenting, whereas exploitation is concerned with such activities as refinement and implementation [7]. Even though exploration is most often associated with radical and disruptive innovation, it is exploitation that creates distinctive competence and an appropriation of gains from exploring new fields of knowledge [2]. Therefore, the focus during innovation should be on constantly finding the optimal balance between the two groups of activities, not on choosing one over the other. The codification approach has been shown to favor the down-stream product development phase, whereas personalization has been found to fit better with the front-end phase [2].

The second challenge is balancing the existing knowledge with the absorption of new knowledge. For the front end, flexibility and fast adoption of new knowledge domains is important for the creation of new technological paths. However, large bodies of existing knowledge can be a significant inhibitor for creating these new paths. This feature is what Leonard Barton [53] referred to as *core competencies*, which turn into *core rigidities*. In the product development phase, the issue is reversed: the ability to absorb and refine knowledge within a domain is directly supported by the existence of in-depth knowledge within a similar domain in the company [54].

The last challenge is balancing the different information needs for handling radical uncertainty, calculable uncertainty, and equivocality. As radical uncertainty is not non-quantifiable, its assessment becomes reliant on the ability of managers to make sense of patterns of weak signals at any given time. However, this approach is resisted by the formalized decision-making processes, which are traditionally built around assessing risk [33, 55]. These processes are efficient tools for objective portfolio management when the project

is mature enough to be assessed, and in these situations, intuitive pattern recognition often fails [55]. Furthermore, it is challenging to distinguish uncertain and equivocal situations from each other, which is essential because the information acquisition lowering uncertainty can increase equivocality.

From this overview, it is found that further empirical research is needed to evaluate the completeness of the above list of knowledge management challenges, to explore how they change from the front end to the product development phase and, finally, to elaborate the understanding of these challenges during an innovation process. From the literature review, it is also apparent that not much is known about knowledge management during the transition phase.

3   RESEARCH METHODOLOGY

The case study methodology was selected for this study as the aim was to investigate the operational links between knowledge management challenges and the process of innovation. Therefore, the natural form of the research question is a "how" question, which indicates that the case study methodology is appropriate [56]. Furthermore, the insights needed into the complex social processes inherent in managing multiple innovation modes simultaneously would be hard to reveal through a solely quantitative methodology. In theory building from case studies, the theory building occurs via recursive cycling among the case data, the emerging theory and later extant theory [57], which enables the creation of an explanatory model of knowledge management challenges in moving from the front-end of innovation to product development. During the study, the corresponding author was employed in the case company for a total of four years, which gave the perspective of inquiry from the inside [58] . The choice of the company to study for the research was driven by the need to study innovation in an incumbent context innovation, including disruptive innovation, would be likely to take place. A further condition was that the company should have a long history, making it possible to observe the expected challenges of unlearning old knowledge. A Danish energy utilities company was chosen, as they are undergoing significant changes along at least three dimensions of contextual conditions: 1) *Technology* is changing into environmentally sustainable platforms with high flexibility regarding primary fuels; 2) *regulatory frames* are becoming increasingly flexible and; 3) the market is turning toward a significantly increased *consumer agency*, meaning that energy consumers are changing from passive to active consumers and, in some cases, becoming local producers [59]. In effect, the arena of product, service and product-service system design in this company is undergoing radical change. Thus, these formed the reasons for the choice of

this company for a single-case study, as the process of interest for the study is expected to be particularly transparent in this case [56, 60]. The company is structured as a group with the following five business units: 1) exploration and production of oil, 2) production of electricity, 3) commissioning of wind farms, 4) sales and distribution of electricity to private and wholesale markets, and 5) trade of oil, gas, coal and electricity on the Nordic and European markets. Data for this study were collected at the group R&D level, which is a part of the executive support group that reaches across all business units. Furthermore, data were also obtained from key stakeholders in the innovation projects from each business unit. The sources were all involved in one or more of the following projects:

Inbicon aimed to develop the mechanical technologies that are required to produce 2nd generation bioethanol from straw on an industrial scale. The technology is based on commercially available enzymes and builds on a long prehistory of knowledge generated from the pre-treatment of straw for combustion.

Renescience aimed to develop the mechanical and enzymatic technologies that are needed to pre-treat normal household waste from a landfill to synthesize gas that is comparable to natural gas. The technology builds on the knowledge generated within the Inbicon project.

Pyroneer aimed to create synthesis gas on a large scale via the thermal gasification of a wide range of biomass sources, including types of biomass that are not suitable for enzymatic processes. The Pyroneer project builds on knowledge from thermal power plants and employs a patent that was externally acquired from a researcher.

Powerhub/VPP aimed to balance the electricity grid via the rapid and efficient control of small units that either produce or use electricity by bundling them into virtual power plants. Powerhub/VPP builds on knowledge obtained from the generation of large amounts of wind power since the 1980s.

BetterplaceDK aimed to develop standards and infrastructure for charging electric vehicles in DK and through Betterplace in the rest of the world. BetterplaceDK builds on knowledge regarding grid integration and balancing services as well as the external partnership with Betterplace.

Etrans aimed to develop the value chain for electric mobility and to explore concepts related to electric mobility services for end-users. Etrans builds on knowledge regarding demand-profile modeling and sales as well as an external consortium-collaboration with 14 other industrial partners.

Together, these innovation projects cover incremental, radical, and potentially disruptive innovations. In particular the *power hub* and *betterplaceDK* have the potential to have disruptive effects: a successful introduction and maturation of these two technologies would render the largest business unit (large coal-fired power plants) as these would no longer be profitable. The company was aware of this and started selling off thermal plants and their thermal power R&D units during the project period. In order to accommodate this kind of projects, the group R&D unit was structured as a separate autonomous unit, which was only connected to the business units through potential collaboration on innovation projects.

3.1 Data Collection

Data were collected from a total of 83 participants by means of workshops and interviews. The participants were sampled through the roll-the-snowball method, in which each participant was asked to provide contacts

to other people that might be of interest for the study and are directly involved in disruptive innovation projects [61]. All participants were highly knowledgeable about innovation projects in the company, and the three-phase corporate innovation process model. However, due to allocation of responsibility and company history some informants were more knowledgeable in one or more specific phases (See Table 4).

Table 4: Informants' familiarity with the innovation phases

	Interviewees	Workshop 1	Workshop 2	Total
Phase 1: Front End	2	10	18	30
Gate: Transition	All	All	All	83
Phase 2: Product Development	3	8	27	38
Both Phases	1	5	9	15

Project documentation from the company's intranet was used as secondary information to corroborate data gathered in the interviews and workshops.

A total of six face-to-face interviews of 1-1½ hour duration were carried out with innovation managers. All interviews were undertaken in a semi-structured manner. An interview guide with precise questions was prepared based on the literature and followed in each interview. During the interviews, the interviewees were allowed to expand on their answers, and the interviewers probed further into interesting topics as they arose. The interview guide consisted of questions in the following categories: 1) personal networks and their function; 2) the interviewee's understanding of innovation, knowledge, and decision making; 3) personal narratives on knowledge flow and decision making and; 4) experience with methods and tools for decision making, innovation support, and knowledge management. During the interviews, participants were asked to describe concrete innovation projects phase by phase, according to the process-model that the company itself applied. These phases were later translated to common academic concepts during analysis.

All interviews were transcribed for data analysis. The use of interviews had the benefit of providing data from a wide range of past events in the disruptive innovation projects. However, interviews have the limitation that the data is affected by recollection bias, and is retrospective in nature. This issue was addressed through the use of secondary data and workshops, in which recollection bias is minimized due to the large sample size as all utterances were verified or corrected by other participants.

Two workshops were conducted (see Table 5). One was staged and facilitated by the authors, and the other was staged and facilitated by the company itself with the researcher present as observer [62]. All of the material produced in the workshops was collected for data analysis.

Table 5: Comparison of characteristics of each workshop

Characteristics	Workshop 1 - Knowledge in Innovation	Workshop 2 - Balancing Structure and Creativity
No. of participants	23 people in 4 groups	54 people in 10 groups
Type of participants	Development function at the management, project management and specialist levels	Development function at the management, project management and specialist levels
Topic(s)	How may knowledge be structured and made accessible for innovation? How may knowledge sources be identified and activated in innovation? What are the criteria for evaluating the quality of KM methods?	Create ideas for enhancing innovation by balancing structure and creativity.
Duration	7 hours	6 hours
Preparation	20-minute introduction to KM in innovation and 3- to 5-minute explanation of tasks.	45-minute lecture on a mental model describing roles of structure and creativity in innovation.
Staging	Research group staged and facilitated	Case company staged, consultant facilitated
Facilitation	Structured around the three topics with prescribed brainstorm approach and discussions in plenum	Open-ended facilitation, with groups choosing their own methods, presentations in plenum.
Collection of data	Produced material, structured by the participants, captured on post-it notes, flipcharts and posters.	Produced unstructured material captured on large post-it notes with explanations
Amount of data	189 codeable segments	259 codeable segments
Treatment of data	Coding	Coding

In workshop 1, all of the participants received a 20-minute presentation in which the authors presented the research project as "an exploratory study of the innovation process" and gave a short introduction about how innovation may be defined in terms of the successful integration of knowledge from different domains [27]. The presentation provided the participants with enough background information to understand the general purpose of the workshop and three tasks while still maintaining hypothesis blindness. After the presentation, the participants were split into 4 groups, each replicating exactly the same tasks. For all three tasks, the participants were given a 5-minute scripted introduction and handout in the form of a postcard with the main questions (see Table 5, "topics") and a few lines of supplemental information. In addition, A0 posters with pre-printed empty matrixes were distributed to all of the groups. Each task was timed to last 1½ hours, followed by a 5-minute plenary presentation by each group for each task. After these presentations, all of the matrixes with post-it notes attached to them were collected as data. An example of a task was to brainstorm ways (methods) to manage knowledge, based on challenges the participants were facing in their daily work.

Workshop 2 was arranged by the company itself; hence, the authors had very limited influence on the participants during the workshop. The workshop began with a 10-minute welcome by the head of the innovation center, followed by a 45-minute lecture from an external consultant that explained an innovation model called the innovation diamond [63]. Afterwards, the participants were divided into 10 groups, and they completed two brainstorm exercises, each lasting 1½ hours. During these sessions, the participants had to come up with suggestions on how to balance structure and creativity, and they shared ideas on best practices with

their group members. To facilitate this process, the consultant supplied an inspirational toolbox with such methods as a negative brainstorm (consider how to make the situation worse) and association cards (consider how Elvis and Einstein would have addressed the task), among others. After each exercise, the suggestions from each group were presented in plenum, and the suggestions were collected as data for the analysis.

3.2 Data Analysis and Coding Scheme

First, an initial coding scheme was created by eliciting codes from applying the knowledge-based view on innovation processes, thus the initial coding scheme corresponds to Eisenhardt's [60] a priori constructs and Miles & Huberman's [62] conceptual framework. The use of an initial coding scheme connected the study closely to existing theory, through a set of basic codes and categories. Next, the coding scheme was developed further by analyzing the empirical data to verify or reject the initial codes and categories and to create new codes and categories. Recurring themes linking the expressions found in the three data-sets were identified through three primary code identification techniques: Repetitions, cutting and sorting, and similarities and differences, as they have been proposed to have strong fit with the textual verbatim data collected, while also supporting both rich narratives (interview data), and brief descriptions (workshop data) [64]. This combined questioning and further development of the coding-scheme had the benefit of limiting the bias caused by forcing findings into a solely predefined coding scheme [60].
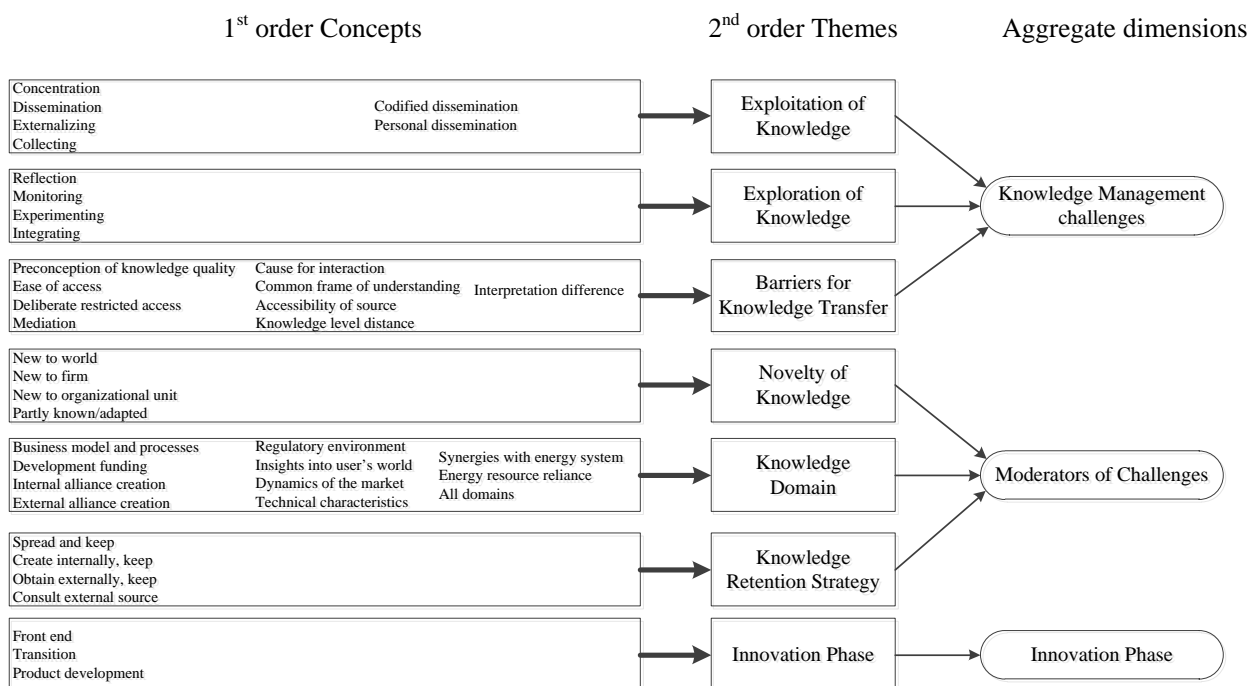
Figure 2: Data Structure, formatted according to [Gioia]

The codes were subsequently categorized into larger and larger categories in an iterative process between the three data-sets and theory, in line with [26, 60, 62]. In Gioia's terminology, first order concepts were created as described above as mutually exclusive codes and the second order themes were created by categorizing these codes. Finally, the aggregate dimensions were created by grouping the categories (second order themes) into challenges and moderators for knowledge management (see Table 6). This process ran iteratively back and forth between the levels of abstraction until a satisfactory grounded structure was achieved (see Figure 2 and code definitions in appendix 1).

Table 6: Categories identified and/or confirmed by the empirical data - key literature provided as reference

Category	Definition and central clarifying literature
Innovation Phase (Basis for comparison)	Reference category describing the phase in the innovation process to which the data relates. See Introduction for more details on this particular division of the innovation process [27, 31, 65].
Exploitation of Knowledge (Challenges)	A group of activities concerned mainly with transferring existing knowledge through teaching, mixing teams, and capturing information in databases. This is the main concern in most of the KM literature [2, 66-68].
Exploration of Knowledge (Challenges)	A group of activities aimed directly at managing new knowledge: how to create it, identify it, and integrate different knowledge from different domains to put it to use [2, 31, 69].
Barriers for Knowledge Transfer (Challenges)	Identified types of issues involving transferring knowledge, encompassing situations where the transfer is directly from person to person, as well as situations where knowledge is explicated into reports, guidelines, databases, and emails as part of the transfer. Transfer of tacit, implicit and explicit knowledge types all appear within this category [18, 45, 67].
Novelty of Knowledge (Challenge moderator)	Novelty level of the particular knowledge that is handled by the business developers. The scale ranges from knowledge completely new to the world to common knowledge that is re-used in a different context [2, 27].
Knowledge Domain (Challenge moderator)	This category defines the object of the above knowledge management activities, being a classification of managed knowledge based on what the knowledge is about. The classification is an extension to distinguishing between market and technology, a distinction frequently used in management literature [68-70].
Knowledge Retention Strategy (Challenge moderator)	Describes the strategy followed to purposefully keep or discard the knowledge in use. The categories range from consulting external sources and not deliberately trying to retain any knowledge to the internal creation of knowledge in the company, for which it is possible to retain all knowledge within the company [45, 67, 68, 71].

The final analysis and theory building was carried out in three steps: firstly, the data was segmented into a total of 1067 data segments. For the interviews, each utterance was considered a segment, for the workshops each post-it note was considered a segment. Secondly, each of the three datasets (interviews, workshop 1 and workshop 2) were coded separately with the coding-scheme, thus the same scheme was applied to all three datasets (see Table 7and 8). Simultaneous coding of data segments into categories related to KM and innovation management was undertaken in order to infer the empirical relationships between these in the final analysis[62]. The analysis of the three datasets was brought together by searching for patterns and differences across all three datasets through identifying co-occurrences of codes in data-segments. Finally, the identified patterns were explaining by going back to the data segments in which they occur.

Table 7: Example of six coded data segments from the workshops

Specific suggestion on post-it notes from participants	Skill-upgrading of current employees in business understanding	"Numskull Jack" (Klods Hans) - Be yourself	Best practice transfer from other large companies e.g. Novozymes	Concern-understanding across the concern via e-learning	Upgrade and internally prioritize networks	Concern management sponsorship
Question / task posed to the participant	How can the knowledge domains be structured and made accessible?	Presentation of the Idea diamond and common language for innovation-task: develop ideas for enhancing Innovation	How can the knowledge domains be structured and made accessible?	How can the knowledge domains be structured and made accessible?	How can the knowledge domains be structured and made accessible?	What are the requirements we need to evaluate the methods against? - And how should the requirements be measured?
Mapping of suggestion done by participant	Organisational structure+ Personalisation+ Access to knowledge	Specific situation of using mud as sauce mentioned	Organisational structure+ Personalisation+ access to knowledge	Organisational structure+ Personalisation	Personalisation+ repository, not social network	Requirement, connected to challenge site

Categories	Codes (first order concepts)					
Innovation Phase	All Phases	0	Front-end	All Phases	All Phases	0
Exploitation of knowledge	Dissemination	0	Collecting	Dissemination	Dissemination	0
Exploration of knowledge	Integrating	Experimenting	Integrating	Monitoring	Reflection	0
Barriers for knowledge transfer	Interpretation difference	Pre-conception of knowledge Quality	Accessibility of source	Accessibility of source	Lack of common frame of understanding	Lack of mediation
Novelty of knowledge	Existing	Partly Known / Adapted	New to Firm	New to Org. Unit	New to Firm	0
Knowledge domain	Business model and processes	0	Business model and processes	All	All	All
Knowledge retention strategy	Create internally	Create internally	Get externally, keep	Spread and Keep	Spread and Keep	0

Table 8: Example of three coded data segments from the interviews

Segment	you know, (they presented in) the common power point way, but + also in pictures and small movie clips, and so on, I think that **WE HAVE** a data base actually where you can go in and, and you can take different segments and then look into **STATEMENTS** of some of these potential consumers or these folks who were interviewed and then you can see **STORIES** about different statements.	Mmmmmh, you know, I got a network of , of, of , of different mmmh different consultant agencies, and so on. I have a continuous, you know, dialogue, with them. Mmmmh, so- I use what I call brain-picking	Yes, it's , it's, it's, you know, it's when **I** think of innovation it's + with a **CONSUMER** centric perspective , hmmm-

Categories	Codes (first order concepts)		
Innovation Phase	Front end	0	0
Exploitation of knowledge	Codified dissemination	Collecting	0
Exploration of knowledge	Monitoring	Monitoring	0
Barriers for knowledge transfer	0	0	0
Novelty of knowledge	New to Firm	New to Firm	0
Knowledge domain	Insights into user's world	0	Insights into user's world
Knowledge retention strategy	Consult external source	Consult external source	0

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Coder reliability check

As only one coder coded all the data a Cohen's Kappa test was applied to test the reliability of coding across multiple coders. A second coder was given a sample of 60 lines, 20 lines from each workshop and 20 lines from the interviews, which were coded after the meaning of each code had been explained in detail. The frequency of agreement between the two coders was calculated, calibrating for the frequency expected to occur by chance. After this operation, the results were compared to Cohen's empirical values, as shown in Table 9.

Table 9: Calculation of coder reliability

Values Calculated	Workshop 1	Workshop 2	Interviews	Across Data-sets		Cohen's Comparison Intervals	
						Reliability	Interval
F_{obs}	0.786	0.700	0.629	0.705		Fair	0.4 – 0.6
F_{exp}	0.014	0.014	0.014	0.004		Good	0.6 – 0.75
κ	0.757	0.671	0.600	0.70		Excellent	0.75 – 1.0
Reliability	Excellent	Good	Good/Fair	Good			

The Kappa values in all three data sets, as well as across data sets, were found to be satisfactory. There is generally a good to excellent reliability, indicating reliable coding with little bias from the coder. The coding applied to workshop 1 was found to be the most reliable and was categorized as *excellent*. The interview coding was the least reliable, with a score of *good*, but it was approaching a score of *fair*. A possible explanation for the lower score from the interviews is that utterances are more ambiguous than a short precise statement from a workshop; workshop statements were thus uniformly easier to code across all categories. All instances of disagreement between coders were examined, and it was found that the differences could be explained through codes being close together, e.g. there were instances of disagreement between coding something as *new to the company* or *new to the organizational unit*, but there were no disagreements about coding something as *new to the world* or *existing*. This observation may argue for collapsing some of the codes when the coding scheme is used again in the future, e.g. by combining the above-mentioned categories into *new to company or organizational unit*.

4   DISCUSSION OF FINDINGS

In this section, the KM challenges and moderators identified through the thematic analysis are presented. The challenges and moderators are discussed in the order in which the categories appear in Table 10

Table 10: Co-occurrence of themes from the analysis aggregated in overview form.
Values are given as cross-tabulation between categories and phases e.g. front end and exploitation= 100%

Phase	Front end		Transition		Product development	
Categories	Codes (mutually exclusive)	F	Codes (mutually exclusive)	F	Codes (mutually exclusive)	F
Exploitation of Knowledge (Challenge)	Dissemination	21.3%	Dissemination	49.9%	Dissemination	30.3%
	Collecting	31.6%	Collecting	12.7%	Collecting	4.5%
	Externalizing	10.3%	Externalizing	13.0%	Externalizing	48.5%
	Concentration	11.1%	Concentration	11.2%	Concentration	8.3%
	Personal dissemination	24.5%	Personal dissemination	4.4%	Personal dissemination	8.3%
	Codified dissemination	1.2%	Codified dissemination	8.8%	Codified dissemination	0.0%
	Total	100.0%	Total	100.0%	Total	100.0%
Exploration of Knowledge (Challenge)	Integrating	37.7%	Integrating	60.5%	Integrating	22.2%
	Reflection	12.9%	Reflection	22.7%	Reflection	29.2%
	Experimenting	18.7%	Experimenting	1.4%	Experimenting	0.0%
	Monitoring	30.8%	Monitoring	15.4%	Monitoring	48.6%
	Total	100.0%	Total	100.0%	Total	100.0%
Barrier for Knowledge Transfer (Challenge)	Pre-conception of knowledge quality	7.8%	Pre-conception of knowledge quality	4.3%	Pre-conception of knowledge quality	0.0%
	Ease of access	2.5%	Ease of access	5.7%	Ease of access	0.0%
	Deliberate restricted access	1.9%	Deliberate restricted access	0.0%	Deliberate restricted access	13.6%
	Lack of mediation	25.1%	Lack of mediation	8.1%	Lack of mediation	11.1%
	Cause for interaction	20.2%	Cause for interaction	18.2%	Cause for interaction	5.6%
	Lack of a common frame of understanding	19.3%	Lack of common frame of understanding	47.8%	Lack of common frame of understanding	50.5%
	Accessibility of source	14.5%	Accessibility of source	7.7%	Accessibility of source	13.6%
	Knowledge level distance	2.9%	Knowledge level distance	6.7%	Knowledge level distance	5.6%
	Interpretation difference	5.9%	Interpretation difference	1.4%	Interpretation difference	0.0%
	Total	100.0%	Total	100.0%	Total	100.0%
Novelty of Knowledge (Moderator)	New to organizational unit	31.0%	New to organizational unit	42.9%	New to organizational unit	10.8%
	New to world	25.7%	New to world	4.3%	New to world	9.1%
	New to firm	26.9%	New to firm	7.9%	New to firm	0.0%
	Partly known/adapted	7.2%	Partly known/adapted	28.6%	Partly known/adapted	37.5%
	Existing	9.2%	Existing	16.4%	Existing	42.6%
	Total	100.0%	Total	100.0%	Total	100.0%
Knowledge Domain (Moderator)	Business model and processes	32.6%	Business model and processes	32.0%	Business model and processes	67.7%
	Development funding	0.4%	Development funding	1.4%	Development funding	0.0%
	Internal alliance creation	8.9%	Internal alliance creation	20.5%	Internal alliance creation	9.5%
	External alliance creation	4.1%	External alliance creation	0.0%	External alliance creation	0.0%
	Regulatory environment	1.5%	Regulatory environment	0.0%	Regulatory environment	0.0%
	Insights into user's world	1.8%	Insights into user's world	7.7%	Insights into user's world	0.0%
	Dynamics of the market	2.6%	Dynamics of the market	9.1%	Dynamics of the market	0.0%
	Technical characteristics	2.2%	Technical characteristics	3.8%	Technical characteristics	0.0%
	Synergies with energy system	2.9%	Synergies with energy system	1.4%	Synergies with energy system	0.0%
	Energy resource reliance	1.1%	Energy resource reliance	0.0%	Energy resource reliance	0.0%
	All domains	42.0%	All domains	24.0%	All domains	22.7%
	Total	100.0%	Total	100.0%	Total	100.0%
Knowledge Retention Strategy (Moderator)	Spread and keep	21.6%	Spread and keep	53.6%	Spread and keep	57.8%
	Create internally, keep	50.1%	Create internally, keep	46.4%	Create internally, keep	32.2%
	Obtain externally, keep	14.7%	Obtain externally, keep	0.0%	Obtain externally, keep	10.0%
	Consult external source	13.5%	Consult external source	0.0%	Consult external source	0.0%
	Total	100.0%	Total	100.0%	Total	100.0%
	Total Front-end	75.5%	Total Transition	15.68%	Total Product development	8.82%

Table 10 shows the cross-tabulated and aggregated results in matrix form, with the numbers in the frequency

of the codes given in the F columns. The frequency is calculated as a percentage of the total category within

the phase. For example, in the top left corner, code dissemination accounts for 21.3% of the total hits of ex-

ploration within the front-end stage. Within each the results of the cross-tabulation are shown, with the high-

est values needed to arrive at a cumulative frequency of minimum 75% shown in gray. These numbers show

repetitions of co-occurrence of the codes in each of the innovation phases. Though a high number equals a frequent repetition and thereby a reason to look for a pattern, surprisingly low scores or highly differing scores of a code across the phases are equally valid reasons to look further for patterns in the data.

4.1 General findings

A graphical representation of the results from Table 10 is provided in Figure 3, where each category of challenges or moderators contains three graphs, one for each of the innovation process phases.
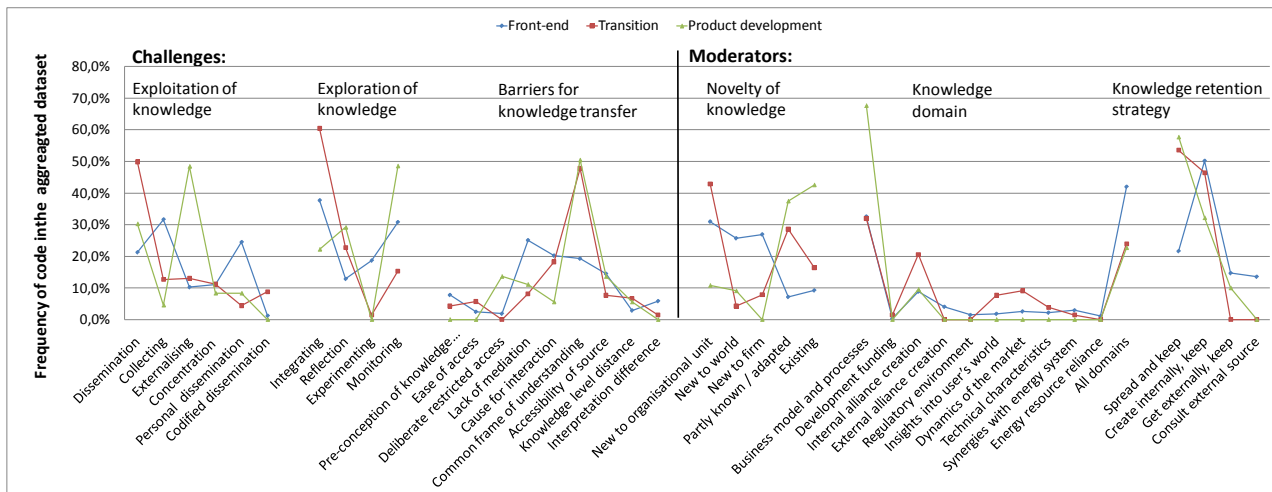
Figure 3: Graphical representation of how often each code appear in the data for each of the three phases

Starting from the left side of Figure 3, the first category corresponds to the first level of Table 10 (exploitation of knowledge), the second category to the second level (exploration of knowledge) and so forth.

From examining Figure 3 to identify the single largest challenge and moderator in each category during the front-end phase, it is found that the challenges *collecting, integrating, and lack of mediation,* and the moderators *new to organizational unit, across all domains and create internally for keeping* have a frequency above 25% in their respective categories. These results characterize the front-end phase as an open phase in which knowledge is created, combined and integrated via personalization, with the central challenge being to device methods for integrating knowledge across all domains, in particular with focus upon knowledge that is new to the company.

For the transition phase, the same exercise identifies the challenges: *dissemination, integrating, lack of common frame of understanding* and the moderators *new to organizational unit, business model and processes,* and *spread and keep* with all of the codes having a frequency above 30% in their respective categories. These results characterize the transition phase as a communication-intensive phase in which knowledge is hand-

ed over primarily via personalization and some codification, with the central challenge being to create a common frame of understanding and to make ideas fit with current business models and processes, enabling integration with the existing business and creation of internal supportive alliances.

Finally, for the product development phase, the challenges identified were *externalizing, monitoring, lack of common frame of understanding* and the moderators were *existing, business model and processes* and *spread and keep*, all having a frequency of above 40%. These results characterize the product development phase as a closed phase in which existing knowledge is explicated and the main focus is on the defined project-goal. Thus, the central KM challenge in this stage is to create a common frame of understanding, enabling the project to monitor the surrounding context more openly to reflect on the continued validity of the goals while sharing the perception of the context with other projects to spread and test knowledge internally.

4.2 Specific challenge: Exploitation of Knowledge

The category *exploitation of knowledge* in Figure 4 shows that throughout the innovation process, the trends of *personal dissemination* and *collecting* are gradually phased out and overtaken by an exponential increase in *externalization*. As expected, the general *dissemination* peaks during transition, while *codified dissemination* never really takes off, which seems odd, as it would be expected to follow *externalization.* The explanation for this phenomenon was found to be that codified knowledge sharing, e.g., via document handling systems, was considered rather useless by the participants, while efficient externalization of knowledge was required for other purposes, such as archiving for legal issues and quick contributions to annual reports.
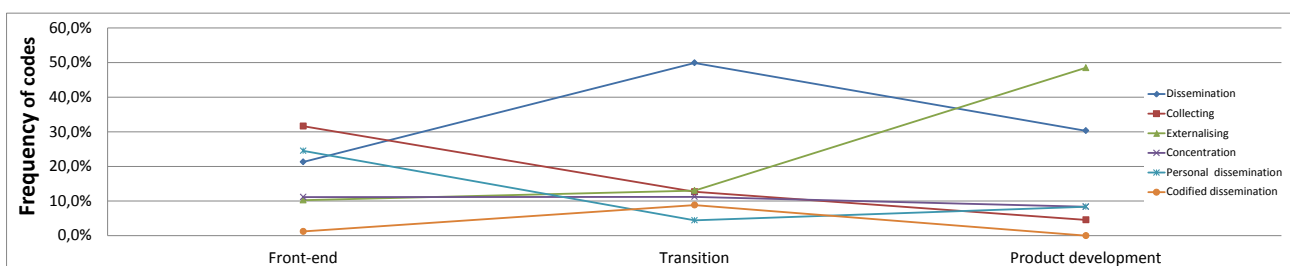
Figure 4: The exploitation of knowledge codes, shown as functions of the three innovation phases

Efficient exploitation of knowledge is one of the cornerstones of KM theory [68]. The analyzed case is no exception; however, there is clearly a more diverse focus on different exploitation activities in the front-end and transition phases than in the product development phase. From the interviews, it is clear that support for exploitation activities are high on the agenda in the company, as they see KM as similar to knowledge shar-

ing. Knowing that there are challenges involved with handling new knowledge, they try to solve the challenges through the known exploitation-supporting approach, which has turned out rather efficient in the product development phase in the past. However, it was found to be inefficient in the front-end phase, as the central challenge here is exploration. This finding is consistent with Berends [2], who suggested that a focus on exploitation activities in radical new innovation (especially when new ideas are conceived) is often overemphasized, whereas focus on strengthening the exploration activities should be emphasized to a greater extent.

4.3 Specific challenge: Exploration of Knowledge

Analyzing the category *exploration of knowledge* across the innovation process revealed the trend that *experimentation* is gradually phased out and overtaken by *reflection*, while *integration* starts as the highest category in the front-end phase (see Figure 5). Integration is even more important during the transition but drops when moving into the product development phase, where *monitoring* is the central exploration challenge.
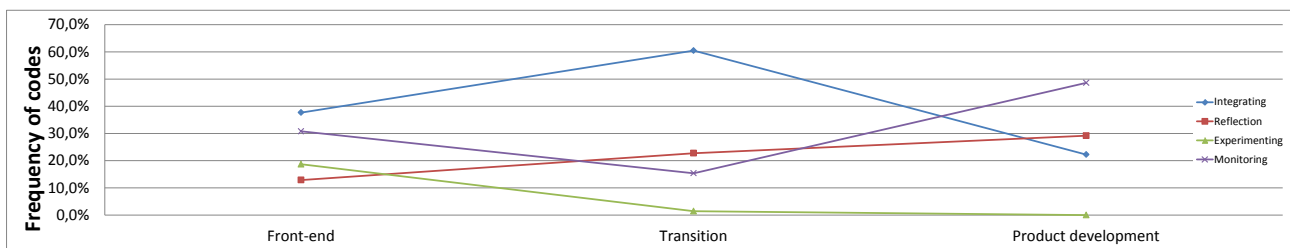
Figure 5: The exploration of knowledge codes, shown as functions of the three innovation phases

As mentioned above, this category is shown to be particularly important in the early phases of innovative work [2]. However, in this case, there was very low explicit focus support for exploratory activities. When support for the exploration challenge was provided, it was driven by reactions to problems more than deliberate proactive support for exploration of unexplored domains. Again, in this category, clear changes throughout the innovation process are seen, where the knowledge-creating activity *experimenting* is only seen as a challenge in the front-end phase. Furthermore, from the qualitative analysis, experimentation was identified as a challenge, even in the front end, as there is often a need to experiment with large sociotechnical networks. One interviewee described how he would love to acquire an electric car to experiment with the services designed for it, but he said that it makes very little sense to get one because it is actually the whole infrastructure around the car that he would like to be a part of and would like to observe a large population of international users to respond to.

In the product development phase, following what others are doing through *monitoring* appeared as the central challenge. This observation is further supported by frequent statements from the interviews; the participants described project execution as "putting your nose in the track and running".

The code *integrating* appeared only in the front-end and transition phases, and was most commonly repeated during transition. However, there are actually two different challenges hiding behind the numbers. In the front-end phase, the integration challenge relates to integrating knowledge from several different and often new domains of knowledge. In the transition phase, the integration challenge is distinctively between the truth of the company and the new truth that comes with a radically new project idea. In effect, the company is open to trying new paths and venturing into new knowledge domains from the start – however, when projects need to be formalized based on the front-end work, integration into the current business becomes a central issue.

4.4 Specific challenge: Barriers for Knowledge Transfer

Across the innovation process phases, the analysis of *barriers for knowledge transfer* revealed a trend in which *cause for interaction* and *pre-conception of knowledge quality* are gradually phased out and replaced by *common frame of understanding* (see Figure 6). The action-oriented *mediation* starts in the first phase as the most common barrier but decreases rapidly in the two last phases. A central finding in this category was that a need for *common frame of understanding* was present across all categories.
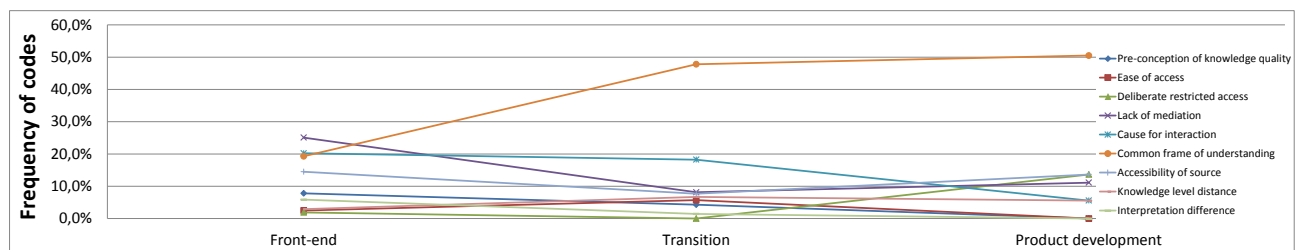
Figure 6: The barriers for knowledge transfer codes, shown as functions of the three innovation phases

Although integration between knowledge domains was identified as a challenge in the front-end phase, the focus on a *common frame of understanding* was considered less of a challenge here than in the subsequent phases. The explanation for this rather odd phenomenon lies in the *mediation* scores, which were very high in the front-end phase compared to other phases. The front-end work is very multidisciplinary by nature, and the involved actors were aware of this. Therefore, though they would wish for a *common frame of under-standing*, they were aware that it was very unlikely to happen and instead focused on the more action-

oriented *mediation*; in the absence of the common frame, a good translation between domains was the next best thing. However, for the transition and product development phases, the strongest focus was on the frame itself, as it was perceived as possible to generate innovation through continuous organizational learning. The challenges are all related to creating a shared understanding of knowledge as opposed to getting better access to knowledge sources, thus equivocality is a central issue. This is further support by a suggestion from the workshop one where "hybrid codification/personalization KM methods are suggested with the rationale that "the reports never really seems to enough on their own". Also, one interviewee described how innovation projects often changed "internal buyer" without considering the significant amount of rework that went into bringing new people onboard, as the project management models has complexity and risk build in as the two central considerations during a project. As a consequence, situations of equivocality were routinely addressed as uncertainty. These findings indicated that the *barriers for knowledge transfer* challenge was related to boundary spanning and may possibly be addressed by a boundary object [72] or brokering [73], combined with a formal recognition of equivocality by building considerations about it into process management system.

Cause for interaction begins relatively high and then tapers off in later phases. This challenge is related to the exploratory role of the front-end activities that occur as people monitor the eco-system around the company closely, causing interactions (ideas for discussion) e.g. in the form of conferences within the field of expertise. From an aggregated analysis of the codes, the barriers to knowledge transfer are seen to pose the largest challenge during the transition, most likely because of the many knowledge-handover situations occurring between the two phases.

4.5 Challenge moderator: Novelty of Knowledge

Figure 7 shows the codes for the category *novelty of knowledge* across the innovation process phases and shows that *new to the firm* and *new to the world* are rapidly phased out and replaced by *existing* and *partly known/adapted*. These types of knowledge already begin to dominate in the transition, with full dominance reached in the product development phase. *New to organizational unit* starts as the highest of all, climbing to a peak during the transition before dropping in the product development phase.
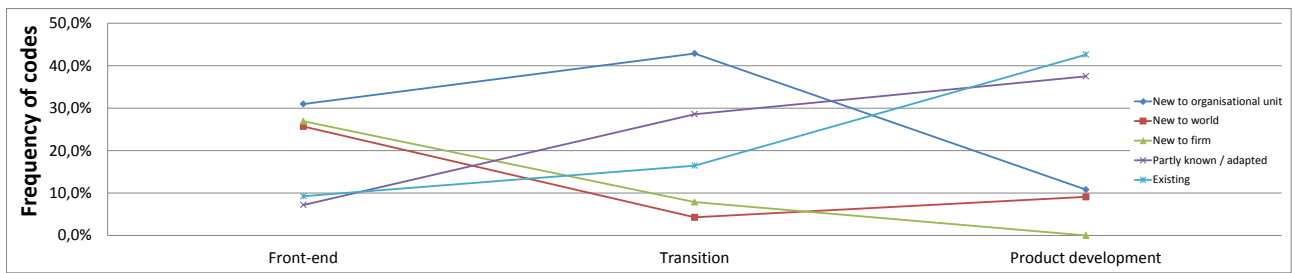
Figure 7: The novelty of knowledge codes, shown as functions of the three innovation phases

The category looks very much as one would expect from a traditional closed innovation model [27], with a strong focus on radically new types of knowledge in the front-end phase and the categories *new to world, new to firm* and *new to organizational unit* making up 84% of the aggregated focus. Between the transition and the product development phase, the focus on new types of knowledge disappears and instead proceeds with existing and partly known knowledge, mainly infused in a waterfall manner from the preceding front-end phase. This picture seems a bit odd considering the fact that the case study company is promoting open innovation [74] that should focus on just the opposite, namely, integration of *new to the firm* knowledge throughout the lifespan of a project and close alliances with external partners. The explanation given in the interviews is that the leaders of the innovation department see open innovation as a viable and unavoidable path for developing the future energy systems, as no one company can change the full system alone; innovation covers an immense amount of business areas, but only a few of these areas are of interest to any one energy utilities company. A possible explanation may be that there is a great amount of inertia in a company this size, and there are very few practically applicable methods at the time for actually practicing and managing open innovation at the start of the product development phase. Thus, the transition to efficient open innovation is challenging.

In the transition phase, there appears to be an opening at least for *new to organizational unit* knowledge; however, behind this number lies the explanation that knowledge that is *new to the unit* is in fact the knowledge that comes from the front-end phase as part of a hand-over; the knowledge only comes from the external world to a limited extent.

4.6 Challenge moderator: Knowledge Domain

The *knowledge domain* category was analyzed across the innovation process phases (Figure 8). The analysis indicated that the broad majority of domains receive very little individual focus, except for the two domains

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business model and processes, *internal alliance creation.* However, *all domains* receive repeated attention, emphasizing that none of the domains are irrelevant, even though there are not singled out.
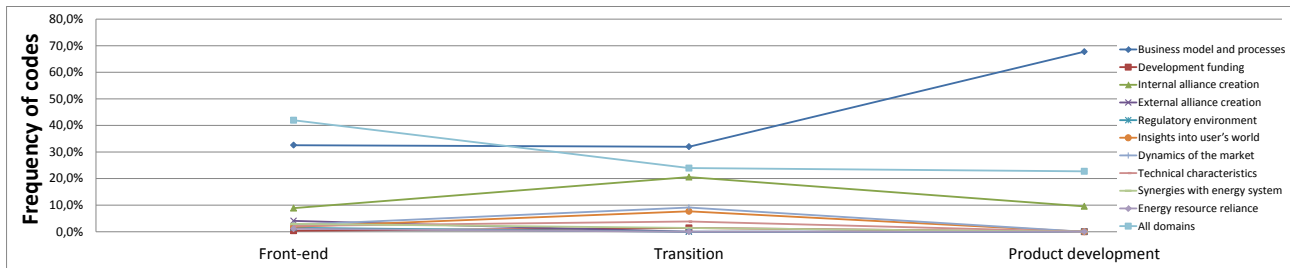
Figure 8: The knowledge domain codes, shown as functions of the three innovation phases

The code *all domains* start as the highest, drops in the *transition* phase and maintain this level in the *product development* phase. *Business model and processes* start at 32.6%, maintain that level in the transition phase, and doubles during the product development phase. The domain *internal alliance creation* peaks at 20.5% during the transition phase after coming from a base level of less than 10%.

In the front-end phase, there is a strong emphasis on *all domains*, which does not mean that all of the domains are equally important, as two are specifically singled out, but rather that *all domains* is an especially strong moderator of challenges. This finding strongly supports the claim above that integration, mediation and experimentation between knowledge domains are of greater significance than any one of the domains in isolation. The *business model and processes* domain is central across all phases. There are two primary causes for this observation: first, as the company struggles with expedient methods for open innovation in an energy system in transformation, it is very cautious about *how* to develop project ideas. Second, as the importance of *internal alliance creation* also suggests, the internal sale of the developed project idea has a strong impact on the *barriers for knowledge transfer* challenge, but it requires intimate knowledge about the many development methods and business models followed by the receiving business units. If a project is based on an unfamiliar development method or is in opposition to the business model of the receiving business unit, it will be very difficult for the unit to engage in the transition and take over the project.

4.7 Challenge moderator: Knowledge Retention Strategy

The analysis of the *knowledge retention strategy* across the innovation process shows that *create internally, keep* is phased out in favor of *spread and keep*. The latter strategy dominates from the transition phase and on (see Figure 9). *Consult external source* (sourcing, with no deliberate effort made to absorb any

knowledge) is solely used in the front-end phase and dies out afterward, being replaced by *get externally, keep*, which indicates a general knowledge absorption strategy.
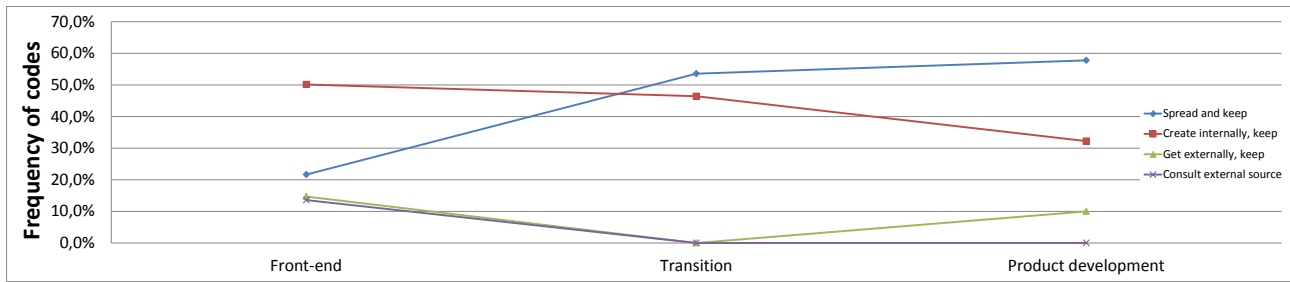
Figure 9: The knowledge retention strategy codes as functions of the three innovation phases

A high level of self-created knowledge and high absorptive capacity makes the company more path dependent, as the competencies needed to create and absorb complex knowledge are the same competencies that will make the company follow a specific technological path [71]. Earlier, it was argued that there was a high degree of path dependency in the projects, whereas the front-end activities are more able to follow, and even create, new paths. Table 10 shows that *spread and keep* starts at 21.6% and rises in the later phases, ending at approximately 60% in the product development phase. *Create internally* shows the opposite trend, moving from 50.1% in the front-end phase down to 32.2% in the product development phase. Together with *consult external*, which appears only in the front-end phase, the numbers support the statement about high path dependency. A common rationale for the high attentions to creating and spreading knowledge in the company was to reduce uncertainty across the organization e.g. through testing equipment and conducting anthropological studies and spreading the knowledge to as many stakeholders as possible. However, in doing so the result was often an unintended increase in equivocality as the variety of interpretations increased.

4.8 Overview of challenges and challenge moderators

This summary of knowledge management challenges and moderators examines the front-end, transition and product development phases of innovation, with the aim of clarifying the most essential insights from the analysis. Thus, it extends the model derived from literature that was presented in Table 3, particularly in terms of evaluating the challenges faced during the transition phase, and how these are affected by the three moderators.
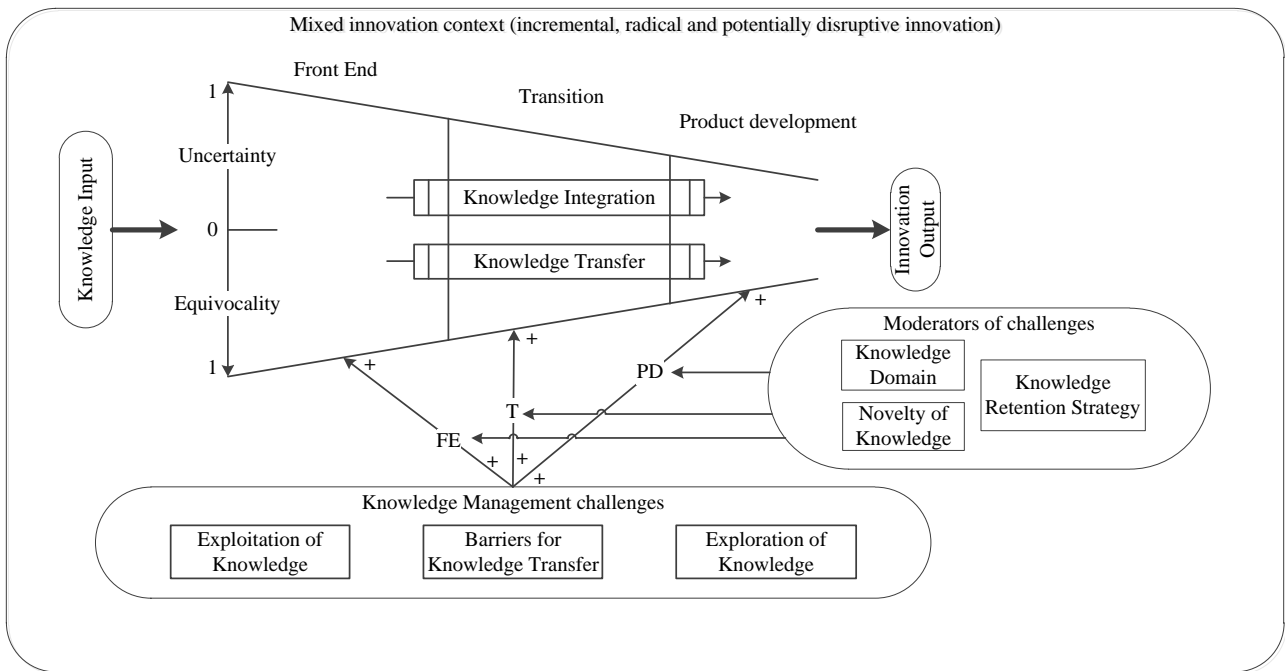
Figure 10: innovation process from the viewpoint of knowledge management challenges

Figure 10 is interpreted from the empirical findings with a KBV perspective on the innovation process. The two sub processes knowledge integration and knowledge transfer drives the innovation process forward, while continuously reducing equivocality and uncertainty. However, this flow is hampered by moderated knowledge management challenges, which affects the stages of the innovation process differently and by common misinterpretations of situations of high equivocality as situations of high uncertainty. The most central of these interaction-effects are presented summarized in Table 11.

Overall, the challenge was to balance (and correctly interpret) the very different knowledge management needs that arise in each phase while still maintaining a coherent knowledge management system and. Thus, the chart should be used as a guide for creating knowledge management methods with the capability of balancing all of the specific needs, rather than a chart from which the single most central challenge or moderator can be extracted. However, it was found that each phase has a particularly central challenge, indicated in Table 11 with gray background. For the front-end it is exploration, for the transition it is barriers to knowledge transfer, and for the product development it is exploitation. The moderators show no affinity towards a specific phase, but affect all challenges in all phases.

Table 11: Summary of knowledge management challenges

Front end	Transition	Product development
Challenge 1: Exploitation of Knowledge		
Collecting and combining analytical knowledge from codified sources, such as databases, was seen as a key issue in the front end, together with the extensive personal dissemination of knowledge within the perpetually changing network of stakeholders.	Dissemination was found to be the central issue of exploitation in the transition phase – in the sense of "a third way" as neither personal nor codified dissemination was found to be the key issue that needed to be addressed.	Externalizing knowledge in a form allowing for combination with existing knowledge in the company is the key issue. This finding is true for the product-related knowledge as well as for the process knowledge, as integration with an existing portfolio of products and methods is essential.
Challenge 2: Exploration of Knowledge		
Integrating and monitoring knowledge proved to be the repeated issues, as efficient monitoring and integration of highly complex knowledge relies on specialist knowledge within the domain, which sacrifices flexibility.	The issue of integration and reflection increases substantially in transition. Integration is essential for the hand-over to strengthen the project and avoid losing knowledge, and reflection support is essential for clarifying product and process issues.	Monitoring was found to be the most commonly repeated issue of exploration during product development because the risk calculations that are needed at this stage are still built largely on assumptions – it is a late phase, but still many creative tasks are completed which adds to the novelty of the innovation.
Challenge 3: Barriers to Knowledge Transfer		
Lack of mediation and cause for interaction are the two most common issues here, and they share a common root: constantly changing areas of knowledge require active mediation to be captured and a deliberate creation of causes to interact with domains on the fringe.	The focus is on creating common frames of understanding during the transition phase, as the knowledge flows are now changing slow enough for this to be feasible, and most domains that get far enough to be considered for transition represent potential new innovation paths.	Similar to the transition, in product development, the focus is primarily on creating common frames of understanding. During product development, the new knowledge is accepted as a new path, and the challenge lies in transferring procedural knowledge in particular to the executing organization
Challenge moderator 1: Novelty of Knowledge		
Radically new knowledge dominates the front end, and with it come all of the issues related to efficiently creating, absorbing and utilizing knowledge from completely new domains.	During the transition phase, the main issue is that the knowledge from the front end is new to the rest of the organization – new procedural knowledge in particular can create problems because of the high inertia of existing procedural knowledge hindering transfer	Existing knowledge issues dominate: Unlearning of existing knowledge was found to be mainly related to procedural knowledge, and to enhance the transfer challenge. The reuse or refurbishing of still-valid existing knowledge was mainly product related and is one of the keys to sustained competitive advantage.
Challenge moderator 2: Knowledge Domain		
In the front end, the majority of issues are related to understanding the interplay between all knowledge domains than to any one domain in particular. This is related to the emphasis on searching out knowledge for new paths.	The transition phase is dominated by understanding alliances, business models, and, to a lesser extent, the interplay between all domains. This focus is directly related to the challenge of selling into a plethora of existing business models, which is a central tool for creating a strong alliance.	During product development, the major issue pertains to the creation of a strong business model, as there is a general impatience for a proof of financial sustainability. Interestingly, there is a very low focus on technology – at this point in time, technical issues are expected to be minor obstacles not related to knowledge management.
Challenge moderator 3: Knowledge Retention Strategy		
There is a clear significance of creating knowledge internally that arises from the experience that the level of complex knowledge required in this industry is difficult to procure. Instead, researchers in promising domains were procured to do research internally in the company.	Internal creation of knowledge is dominant, along with spreading and keeping the developed knowledge. During the transition phase, focus is on transferring complex knowledge through a co-creation process in which front-end people engage in joint research with the recipients for effective transfer.	Spreading and keeping the knowledge is the key concern during product development, in which great efforts are made to educate project staff in the new technical knowledge. Internal creation is still a much repeatet focus, however, and it was observed that both product and process knowledge mainly came from internal creation processes.

5 CONCLUSION AND LIMITATIONS

This study was motivated by a gap in literature with respect to knowledge management challenges faced by managers of engineering design teams during the creation of disruptive innovation, and how these challenges change from the front end to the product development stage of the innovation process. Semi-structured interviews have been carried out with six people, and two workshops have gathered date from a total of 77 people, all of which were either engineering designers or engineering design managers involved in disruptive innovation. From these, descriptions of knowledge management challenges during disruptive innovation has been collected and coded thematically with post-defined and predefined codes in an iterative coding process. The analysis indicated three primary categories of knowledge management challenges i.e. exploration of knowledge, exploitation of knowledge and barriers to knowledge transfer. Furthermore, the analysis indicated three primary categories of challenge moderators i.e. novelty of knowledge, knowledge domain, and knowledge retention strategy.

The three categories of challenges were found to be present in all of the three innovation process phases (front end, transition, and product development), however, each challenge had a phase in which it was especially prevalent: exploration of knowledge was most significant in the front end, barriers to knowledge transfer was most significant during transition, and exploitation of knowledge was most significant in the product development stage. Furthermore, the challenges within each category were found to change, depending on the innovation phase. The three moderators were, as opposed to the challenges, not found to be more attached to any one phase or challenge. They were, however, affected by the innovation process phase, in the sense that moderators within each category changed as a function of the innovation process stage.

From the analysis of the codes within the categories of challenges, integration and monitoring of knowledge are key issues to be addressed in the front-end, where a common frame of reference is the central issue in the transition phase. In the product development phase, externalizing knowledge to allow for combination with other knowledge sets is the central issue. Across all phases, the moderating effect of focusing on knowledge between all available domains, not single ones in particular, was found to be most significant.

This research has contributed to the understanding of knowledge management challenges through an empirical study of how exploitation of knowledge, exploration of knowledge and barriers to knowledge transfer relate to innovation process phases in disruptive innovation. Through this empirical understanding, the three

moderating factors novelty of knowledge, knowledge domains, and knowledge retention strategy were identified and their role as moderators for knowledge management challenges described. Specific contributions include: 1) the transition phase between front end and product development is required to be treated as a separate phase in terms of creating knowledge management support, which is a contribution to the literature on knowledge management in innovation and (N) PD processes, where no such stage exists, except in terms of portfolio management and gate. 2) During the management of multiple innovation processes, situations where the equivocality is high are often misinterpreted as situations of high uncertainty, which is caused by the innovation management processes being built with almost exclusive focus on uncertainty. Thereby, management of equivocality is left to the managers and knowledge workers, but without an explicit assignment or tools to support this issue.

For industry, this study creates a foundation for further development of knowledge management support tools, specifically aimed at supporting the changing requirements throughout the phase of innovation.

In Table 11, the overview of knowledge management challenges and moderators is considered to be a useful tool for managers in practice. Through this table, a manager is able to focus the most essential knowledge management challenges, based on the innovation process phase the team is in, and the moderators as contingency factors. Thereby, a balanced approach to the development of tools for supporting exploration and exploitation is supported.

The theory used in this study comes from the general knowledge management literature, and the focus was on the generic phenomenon of managing knowledge during innovation. It is therefore expected that the theory developed is applicable in other settings than the case company as well. However, a limitation of the single-case methodology is that it does not allow for statistical generalizations. Therefore, the authors cannot claim that our findings can be generalized without testing the theory in other contexts. A multiple-case study would be an idea for further research; in such a study, the boundary conditions of the theory could be established.

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Appendix 1: Complete coding scheme (move to appendix as this is only the definitions)

Categorized Codes	Definition
Innovation Phase	
Front end	Covers the early part of the NBD process, in which goals are not yet defined
Transition	Transition of results from the front end to product development
Product development	Goal-directed phase in which a goal and the means to reach it have been defined
Exploitation of Knowledge	
Concentration	Activity concentrating knowledge in a super-node, e.g., a domain specialist
Dissemination	Distribute and share knowledge either in codified or personal form
Externalizing	Activity making people's personal knowledge explicit, e.g., writing words down
Collecting	Adding and combining knowledge in, e.g., a database for later retrieval
Codified dissemination	Transfer of explicit knowledge directly, e.g., by writing an article
Personal dissemination	Transfer of knowledge without explicating it first, e.g., through apprenticeship
Exploration of Knowledge	
Reflection	Processing of new knowledge at the individual or social level to create clarification
Monitoring	Surveillance of knowledge fields and new ideas internally and externally
Experimenting	Creation of new knowledge and ideas through experimentation in a wide sense
Integrating	Combining knowledge with the aim of creating new ideas and concepts
Barriers for Knowledge Transfer	
Preconception of knowledge quality	The recipient's perception of the source as an authority within its domain
Ease of access	How easy the process of establishing a link to a source or recipient is
Deliberate restricted access	Barrier created to protect IPR, strategies and other sensitive information
Mediation	Absence of mediating device, e.g., drawings, or a facilitator that conveys knowledge
Cause for interaction	Lack of reason to interact with potentially interesting knowledge sources
Common frame of understanding	Absence of *social frames* of understanding, e.g., shared business model/vision
Accessibility of source	How able the seeker is *to locate and utilize* a needed knowledge source
Knowledge level distance	Relative distance in knowledge level between the source and recipient
Interpretation difference	Barrier created by significant differences in *cognitive frames* of the people interacting
Novelty of Knowledge	
New to world	Knowledge completely new to everyone in the world
New to firm	Knowledge that is completely new to the firm but not necessarily to others
New to organizational unit	Completely new knowledge to, e.g., the team but not necessarily to others
Partly known/adapted	Partly known knowledge but adapted to a new specific context of use
Existing	Knowledge already known widely in the firm, unit and world in general
Knowledge Domain	
Business model and processes	*How* to develop the idea or technology into an appropriate business concept
Development funding	Knowledge on how to fund a project to develop the ideas or technologies at hand
Internal alliance creation	The political process by which internal support for ideas is generated
External alliance creation	Knowledge about how support, e.g., visions through alliances with universities
Regulatory environment	Process knowledge on how regulatory frame affects ideas/can be affected
Insights into user's world	Knowledge about the behavior of users and the reciprocal effects on innovations
Dynamics of the market	Macro-scale market insights about market forces, entry barriers, and fluidity
Technical characteristics	Micro-level knowledge about the characteristics of the specific technology at hand
Synergies with energy system	Macro-level energy system: Interactions between elements in the power grid
Energy resource reliance	Insights into a strategic energy resource future, e.g., biomass sourcing or wind
All domains	*How* to develop the idea or technology into an appropriate business concept
Knowledge Retention Strategy	
Spread and keep	Obtain knowledge from internal source, thereby spreading and securing it
Create internally, keep	Create the knowledge internally and evolve competencies at the same time
Obtain externally, keep	Consult external sources but learn and develop new internal competencies
Consult external source	No retention – External sources are used to provide specific answers

Innovation in the making:
A longitudinal case study of dynamic capabilities in innovation teams at an energy utilities company

1 Abstract

Disruptive change in markets and technologies is responsible for the birth and death of many large companies. Surviving or even driving, these changes requires incumbent companies to balance the contradictory activities of exploring new knowledge with exploiting existing knowledge to sustain earnings. However, the manner in which capabilities for balancing exploration and exploitation are created at the level of the innovation team is still poorly understood. Our qualitative study follows a mixed-mode innovation process in real time over a period of three years, exploring how innovation teams at an energy utilities company create dynamic capabilities for disruptive, radical and incremental innovation. We found a process in which an ambidextrous team continuously synchronizes exploration and exploitation with business units to maintain their capacity. The primary contribution of this research is a descriptive model showing how knowledge, decision and foresight activities within disruptive innovation are supported by dynamically changing capabilities within four streams of intellectual capital: human, social, organizational, and artifactual. The latter is a contribution to the existing intellectual capital framework.

2 Introduction

Rapid adaptation to changing environments is essential for the survival of incumbent companies, but the capabilities required to create or survive technological disruptions are generally challenged by existing engineering management processes and values that make the company

operate efficiently within its current environment. Whether incumbent companies can survive disruptive changes to their technology base, products, and business models or whether these changes will force them out of existence is a topic currently debated extensively by scholars in the management literature (Burgelman, 2002); (O'Reilly & Tushman, 2007). One way to look at this disruption is to perceive the company as an adaptive system, in need of adapting to an environment that has been disrupted, which frames the challenge as described by (March, 1991):

Adaptive systems that engage in exploration to the exclusion of exploitation are likely to find that they suffer the costs of experimentation without gaining many of its benefits. They exhibit too many undeveloped new ideas and too little distinctive competence. Conversely, systems that engage in exploitation to the exclusion of exploration are likely to find themselves trapped in suboptimal stable equilibria (March, 1991).

Thus, successful adaptation requires both exploitation of current knowledge and exploration of new knowledge. Balancing these two contradictory activities was found by (March, 1991) to be the key organizational capability driving successful adaptation. Currently, a consensus appears to be building among scholars that companies must excel at both activities to adapt and profit from adaption (see, e.g., (O'Reilly III & Tushman, 2011); (Benner & Tushman, 2003);(Teece, 2007);(Gupta, Smith, & Shalley, 2006). Organizational ambidexterity and punctuated equilibrium are alternative strategies for balancing exploration and exploitation of knowledge. Punctuated equilibrium was first to appear in the literature, describing a company that was organized primarily to ensure efficient exploitation but that occasionally conducted exploratory activities, either deliberately (Burgelman, 2002) or when forced to by the context (Gersick, 1991). This idea was later supplemented by (Tushman, Anderson, & O'Reilly, 1997), who developed the concept of the ambidextrous organization as an alternative to the punctuated equilibrium model. According to their study, companies can deliberately pursue both strategies

simultaneously by using an appropriate organizational structure, anchoring the approach at the top management level by training top managers to balance the contradictory natures of exploration and exploitation. The ambidextrous structure addresses the notion of the innovator's dilemma developed by (Christensen, 1997) that as a general matter, large incumbent organizations are limited in their capacity to generate disruptive innovation because their current processes and values force them to focus on sustaining innovations. Where the disruptive innovation creates a future path of making a living, the sustaining innovation is what secures earnings in the present and the trust of shareholders. Disruptive innovation is an innovation that creates a new value network and market, disrupting the steady course of sustaining innovation that occurs within the existing market and value network. In practice, many companies will be mixing these modes of innovation to different extents. Originally, (Christensen, 1997) described how incumbent companies may be overtaken by disruptive technologies. Later, (Christensen & Raynor, 2003) changed the concept from disruptive technology to disruptive innovation as it became clear that disruption could be non-technological, for example generated by a novel business model. Christensen (1997 & 2003) remained pessimistic regarding an incumbent company's ability to survive disruptions, indicating that the only realistic strategy for incumbents is to create independent units for exploiting the disruption created by new entrants.

The general use of the disruptive innovation concept has been criticized by (Danneels, 2004) and (Markides, 2005), among others, who argued that technology, product, and business model innovation must be separated. If only considered on the inter-firm level, the three types of innovations may have the identical disruptive effect but with different managerial implications (Markides, 2005). Separating innovation by type enables researchers to progress further into micro levels of disruptive innovation by providing a meaningful framework in which to describe how capabilities for balancing exploration and exploitation are created. Studies of dynamic

capabilities, i.e., the abilities of a firm to renew resources and competencies in the face of a changing environment (Eisenhardt & Martin, 2000); (Teece, 2007), have been used to describe the managerial implications balancing the mixed modes of innovation. However, we found a gap in the literature regarding the team-level origin of dynamic capabilities for balancing exploration and exploitation in that the research so far has focused on upper levels of management. This conclusion was further supported by (Gupta et al., 2006), who found little insight in the literature into team- and individual-level creation of dynamic capabilities. Additionally, (Danneels, 2010) and (Eisenhardt & Martin, 2000) found that dynamic capabilities remain vague and of limited practical use unless they are made specific through in-depth studies.

Most in-depth studies of the effects of market change on incumbent companies, such as (Burgelman, 1991), (Rosenbloom, 2000) and (Tripsas & Gavetti, 2003), have been based on historical analysis. While we acknowledge what (Williamson, 1999) referred to as the informative value of studying stories about failures, there is a need for real-time studies of the disruptive innovation process. Consequently, the aim of this study is to undertake a real-time study of the mechanisms through which dynamic capabilities that support multi-mode innovation are developed and evolve on the level of the innovation team. Specifically, we will seek to answer the following question:

How does dynamic capabilities develop and evolve on the innovation-team level, and through which mechanisms do they support the innovation process?

3   Theoretical Background

Over the last twenty-five years, firms have been subject to significant institutional pressure to adopt process management, e.g., Lean, Total Quality Management, and ISO 9000 Certifications; however, the substantive benefits from this approach remain unclear (Benner & Tushman, 2003). This pressure has resulted in managers of innovation teams being forced to adopt process management, despite process management being too rigid and inflexible as an anchor for mixed-non-incremental innovation support (Benner & Tushman, 2003); (Christensen, 1997). While the dynamic capabilities view focuses on the ability to change resources (including processes) as the key to adaptation, as opposed to the process design itself (Teece, 2007), (Smith, Senge, Kruschwitz, Laur, & Schley, 2010) noted that one of the essential capabilities of a company facing environmental change is its ability to describe and thereby reflect on its own processes, thus learning from them and improving them in the future. Innovation managers are left with the dilemma that they must create explicit descriptions of their processes and simultaneously resist the pressure to introduce process management.

Since (Van de Ven, Polley, Garud, & Venkataraman, 1999)'s empirical studies of 14 innovation projects in Minnesota, a consensus has begun to grow among scholars of innovation management that the innovation process is inherently messy and difficult to predict (Ferlie, Fitzgerald, Wood, & Hawkins, 2005); (McLaughlin, 2008); (Chesbrough, 2004; Scharmer, 2009). Despite recognizing that processes are messy, a consensus remains that such illustrations are useful as conceptual models of a complex reality (e.g., (Tidd & Bessant, 2009); (Dodgson, Gann, & Salter, 2008); (Davenport, Leibold, & Voelpel, 2007). Therefore, we chose to review a selection of the most prevalent innovation models to extract their core support functions. These functions are then detached from the process management view, in recognition of the inherently messy and

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constantly adapting innovation process and the need for pragmatic support for innovation teams

(see Table 1)

Table 1: Functional view on innovation process support

Innovation model	Knowledge	Decision	Foresight	Reference
Stage gate	Market and technology analysis, idea generation	Initial screening, gates	Ideas, roadmaps, forecasts, preliminary assessments	(Cooper & Edgett, 2008)
Open Stage gate	External network, design, idea generation	Gates, boundaries, validate, design	Define	(Grönlund, Sjödin, & Frishammar, 2010)
Diffusion of innovation	Knowledge, confirmation	Persuasion, implementation decision	Persuasion	(Rogers, 2003)
Minnesota studies	Development	Implementation Initiation	Initiation	(Van de Ven et al., 1999)
Front end of innovation	idea genesis, opportunity analysis, concept and technology development	Idea selection, engine, commercialization	Opportunity identification,	(Koen et al., 2001)
Theory U	Downloading, seeing, sensing	Prototyping, performing	Presencing, crystallizing	(Scharmer, 2009)

Our six selected theories represent both linear and non-linear models, and we have categorized the elements of each model according to their main function. Consequently, some elements belong to more than one category, as they fulfill multiple functions. The result of this categorization is to elicit the three generic support functions of *knowledge, decision,* and *foresight*. Therefore, the result of the analysis is the three support categories derived from the literature. These are: 1) knowledge-related activities, such as creating, utilizing and sharing knowledge, 2) support for decision-related activities, such as methods for selecting the best alternatives and single item selection, 3) foresight-related activities, such as idea generation, future scenarios, and persuading stakeholders to recognize assumptions, goals, and strategies. After defining these three generic support functions defined, we reviewed literature on knowledge management, with the purpose of identifying how the functions could be created.

3.1 Knowledge, dynamic capabilities and intellectual capital

The innovation process is generally accepted to be tightly connected to knowledge and particularly with the acquisition and efficient use of new knowledge (Nonaka, Toyama, & Konno, 2000; Rogers, 2003). A similar view is offered in studies conducted by (Baum, Li, & Usher, 2000; Benner & Tushman, 2003; He & Wong, 2004) in (Gupta et al., 2006), that learning, gradual improvement, and the acquisition of new knowledge are fundamental to both exploratory and exploitative activities. The primary difference is whether new learning occurs along the existing company trajectory or along a new trajectory. Innovation is also described as a function of knowledge (Tidd & Bessant, 2009); described as creating new possibilities by combining different knowledge sets (Tidd & Bessant, 2009). The notion of merging knowledge sets is also used by (Van de Ven et al., 1999), who observed that innovation is a collective achievement accomplished by knowledgeable individuals, and "boundary spanning" is an essential ability for maintaining a group's effectiveness and for developing new products effectively (Ancona & Caldwell, 1992; Carlile, 2002).

In their work on the knowing-doing gap, (Pfeffer & Sutton, 1999) found that organizational performance depends as much on the skill of managers to transform knowledge into action as it does on the knowledge the managers possess. This argument is consistent with a dual focus on accumulation and use of knowledge found in the vein of literature that classifies an organization's knowledge resources as intellectual capital (e.g., (Bontis, 2001; I-Chieh Hsu & Sabherwal, 2011; Subramaniam & Youndt, 2005). According to (Subramaniam & Youndt, 2005), considering different aspects of intellectual capital offers scholars a means to parsimoniously synthesize the approaches through which knowledge is *accumulated* and *used* in organizations. Since Galbraith originally defined intellectual capital as the (intangible) difference

between a company's actual value and its book value, a plethora of definitions have evolved (see (Bontis, 2001) for a review). However, as many of these definitions were developed for specific contexts and evidence from the social sciences, (Mika, 2005) indicated that concepts of knowledge may be contextually bound; thus, we chose to follow the definitions proposed by (Subramaniam & Youndt, 2005), which were developed specifically to assess the effect of intellectual capital on innovation. Following the general consensus in the literature on intellectual capital, (Subramaniam & Youndt, 2005) defined three separate aspects of intellectual capital:

- *Human capital* is defined as knowledge, skills and abilities residing with and utilized by individuals.
- *Organizational capital* is defined as institutionalized knowledge and codified experience residing within and utilized through databases, patents, manuals, systems, and processes.
- *Social capital* is defined as the knowledge embedded within, available through and utilized by interactions among individuals and their networks of interrelationships.

Thus, there are three distinct approaches through which knowledge is accumulated and used within an organization. Each of these is a potential source of capabilities that support the three functions of the innovation process (knowledge, decision, and foresight). Capabilities are defined as "a special type of resource—specifically, an organizationally embedded non-transferable firm-specific resource whose purpose is to improve the productivity of the other resources possessed by the firm" (Makadok, 2001). Based on this definition, Teece, Pisano, & Shuen (1997) have argued that capabilities cannot easily be bought; they must be built.

Within the context of innovation and especially under conditions of highly dynamic markets, it is useful to distinguish between core capabilities as opposed to general capabilities and dynamic

capabilities as opposed to operational capabilities. For a capability to be considered *core* as opposed to general, it has to differentiate the company strategically (Leonard-Barton, 1992). Core capabilities have also been defined by Teece, Pisano, & Shuen (1990) as "a set of differentiated skills, complementary assets, and routines that provide the basis for a firm's competitive capacities and sustainable advantage in a particular business". In this sense, core capabilities seem intrinsically connected to a positive impact on the firm. However, this is not always the case, as core capabilities may easily turn into core rigidities if radical changes occur in the market or technology-base of the firm (Leonard-Barton, 1992). In order to avoid becoming trapped by these core rigidities, a firm needs to possess and develop dynamic capabilities. Dynamic capabilities are the abilities of a firm to renew resources and competencies in the face of a changing environment (Eisenhardt & Martin, 2000), where operational capabilities are addressing "how we earn a living now" (Zollo & Winter, 2002), and may be either core or general. Thus, dynamic capabilities affect the performance of a company through modifying its operational capabilities (Helfat & Peteraf, 2003). It is through developing the dynamic capabilities that a company will be able to create, extend, and modify new ways of working. This view departs to some extent from the early view presented by Teece *et al.* (1997), in which dynamic capabilities were proposed as the ultimate source of competitive advantage and directly connected to sustaining a long term competitive advantage by firms. The view that dynamic capabilities only affect firm performance through operational capabilities allows two essential issues to be adressed: 1) if there is always a capability behind a capability and no effect from interaction with other resources; we will face an infinite regression problem (Cepeda & Vera, 2007) that is solved through attaching the dynamic capabilities directly to the tangible operational capabilities; 2) The resources within a company prior to entering a new market or in the face of radical market change will be considered as having no value, outside their potential

for flexible reconfiguration. This issue is solved by the same linking of operational capabilities this allows for the existing resources to be accounted for in the new market and to some extent being carried over from old market positions. By following this view however, another issue arises: In the original view, dynamic capabilities offered a description of a set of stable capabilities that would predict a firm's competitive advantage in an unstable market. In the re-conceptualized view of (Eisenhardt & Martin, 2000), the dynamic capabilities themselves become unstable, as they consist of rules and best practices which can be copied across organizations and disappear without deliberate strategic intent.

The close connection between dynamic capabilities and knowledge has been established in several independent studies. Eisenhardt & Martin (2000) proposed that as dynamic capabilities are organizational routines, KM processes guide their development, evolution and use. Zollo & Winter (2002) examined the relationship between knowledge creation cycles and dynamic capabilities empirically, and found that dynamic capabilities can be described as knowledge creation. Cepeda & Vera (2007) expanded this work further by examining the relationship between knowledge management infrastructures, dynamic capabilities, and operational capabilities empirically and found significant correlations between these variables. Thus, the link we made between knowledge resources in the form of intellectual capital and dynamic capabilities is underpinned by earlier studies.

In summary, the types of dynamic capabilities in our study are differentiated by the intellectual capital stream(s), thus focusing on the underlying infrastructure behind the development and evolution of dynamic capabilities. We are using the development of technological innovations as the high-level capability to which all of our lower-level dynamic capabilities contribute (e.g. the capability to change the way decisions about new product concepts are made). These dynamic

capabilities only affect the firm through affecting the operational capabilities which are classified

according to the functions of the innovation model as knowledge, decision, and foresight e.g. the

process by which new product concepts are decided upon (see Figure 1)
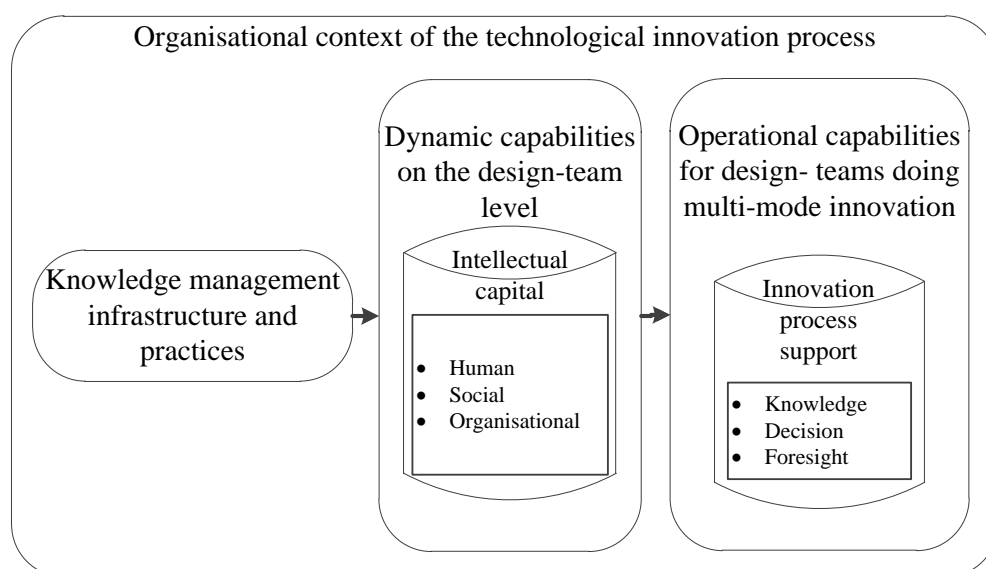
Figure 1: Conceptual model of dynamic capabilities

4   Methodology

Our study was part of a larger research project examining how to support the effective transition

of energy utilities from technologies based on fossil fuels to sustainable technologies. The

specific aim of our study was to investigate how dynamic capabilities for mixed-mode

innovation are created at the team level. Given the sparse existing literature on the subject of

team-level creation of capabilities and the need for a rich understanding of the innovation

process, we chose an inductive research design based on a single case study with multiple

embedded units of analysis, i.e., six innovation projects ranging from incremental innovations to

innovations that had the potential to become disruptive. The inductive approach is described as a

way to reconcile the differences between the two conflicting viewpoints of Teece *et al.* (1997)

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and Eisenhardt & Martin (2000) which researchers within the dynamic capabilities field are separating themselves into (Peteraf, Di Stefano, & Verona, 2013). Hence, there is a need for further inductive studies.

Our embedded design improved the likelihood of creating a rich and accurate theory about the phenomenon, while the single case study sacrifices statistical generalizability in favor of richer detail (Yin, 2002). Furthermore, our sampling within one firm had the advantage of controlling for firm-level factors, such as incentive schemes, corporate culture, national culture and social ties (Martin & Eisenhardt, 2010). We required a company setting that fulfilled three requirements.

1. The innovation process had to be observable in real time over an extensive period of time.
2. We required an incumbent company that was trying to adapt to changing contexts.
3. The process of creating dynamic capabilities had to be transparent and ongoing, which made a company in the nascent stage of building new innovation capabilities preferable.

The Danish energy utilities company DONG Energy was selected as it met all three requirements. Firstly, the company started several innovation projects in response to the societal need for sustainable energy and allowed us unrestricted access to observe their projects. Secondly, the company's history goes back to the time when oil and electricity was introduced into the Danish society; currently, DONG Energy is trying to drive technological disruption by following a strategy to convert at least 85% of its energy production to sustainable sources by 2040. Thirdly, the company was forming an innovation center simultaneously with the start of this study; the innovation center in charge of developing the company's innovation capabilities, which provided an opportunity to study the nascent stage of developing innovation capabilities.

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Therefore, our case fulfills the requirements that a single case study is appropriate when the process of interest is transparently observable and where the case itself is an extreme or unique case (Eisenhardt, 1989; Yin, 2002)

DONG Energy is structured with the following five formal business units: exploration and production of oil (E&P), production of electricity (ThermalPower), commissioning and operating wind farms (WindPower), sales and distribution of electricity to private and wholesale markets (S&D), and oil, gas, coal and electricity trading on the Nordic and European markets (EnergyMarkets). On the group level, we identified the newly started innovation center as an ambidextrous team in charge of multi-mode innovation over the long term (beyond three years). We used the following definition of ambidextrous teams from (O Reilly & Tushman, 2004) as the criterion for classifying the innovation center: "*Ambidextrous teams are structurally independent units with their own processes, structures, and cultures, but are integrated into the existing management hierarchy*". Within DONG Energy, we identified six separate technology innovation projects that were each run by people from the innovation center. From these six projects, the Etrans project was chosen as the primary project to be followed because it would start and end within our three years of observation. Other projects were also followed for three years but in lesser detail when trade-offs had to be made. In this manner, we collected data at two distinct levels: 1) the level of the *innovation center* (IC) as an ambidextrous unit and 2) on a total of six projects from the level of the *innovation team*. Together, we refer to these two levels as the *innovation function*.

As many key stakeholders in the projects, were not accounted for in the formal hierarchical charts of the company, we relied on snowball sampling (Patton, 2001). Over a two-month-long pilot project, we gained the interest of the company in our study and gained access to the

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department meetings in the innovation center. From our observations of these meetings, we identified key stakeholders and upcoming activities in the projects, which we then observed and recorded, stopping when the events identified no longer influenced the innovation projects directly.

In particular, we followed six projects that were run by the innovation centre, these were:

1) *Inbicon* aims to develop mechanical technologies required to produce 2nd generation bioethanol from straw on an industrial scale. The technology is based on commercially available enzymes and builds on a long prehistory of knowledge generated from the pre-treatment of straw for combustion.

2) *Renescience* aims to develop the mechanical and enzymatic technologies that are needed to pre-treat normal household waste from a landfill to synthesize gas that is comparable to natural gas. The technology builds on the knowledge generated within the Inbicon project.

3) *Pyroneer* aims to create synthesis gas on a large scale via the thermal gasification of a wide range of biomass sources, including types of biomass that are not suitable for enzymatic processes. The Pyroneer project builds on knowledge from thermal power plants and employs a patent that was acquired externally from a researcher.

4) *Powerhub/VPP* aims to balance the electricity grid via the rapid and efficient control of small units that either produce or use electricity by bundling them into virtual power plants. Powerhub/VPP builds on knowledge obtained from the generation of large amounts of wind power since the 1980s.

5) *BetterplaceDK* aims to develop standards and infrastructure for charging electric vehicles in DK and through Betterplace in the rest of the world. BetterplaceDK builds on knowledge

regarding grid integration and balancing services as well as the external partnership with Betterplace.

6) Etrans aims to develop the value chain for electric mobility and to explore concepts related to electric mobility services for end-users. Etrans builds on knowledge regarding demand-profile modeling and sales as well as an external consortium-collaboration with 14 other industrial actors.

Table 2: Mapping of projects in technological innovation types

First level	Second level	Projects
(Potentially) disruptive innovation		Etrans, BetterplaceDK, Renescience
Sustaining innovation	Radical innovation	Powerhub/VPP, Inbicon
	Incremental innovation	Pyroneer

In Table 2 a mapping of each project in terms of its innovation height as described in the literature review is provided. The projects covered the entire spectrum of innovation height (see Table 10), thus the theory developed from the understanding of these projects is aimed at a broader innovation imperative and not as such an exploration of one specific type of innovation. The mapping of disruptive innovation is done in terms of "potentially disruptive" based on the projects innovative ability to result in disruption the company itself and society at large. However, as this disruption is yet to take place, this mapping can very well change in the future as markets and technologies develop. These projects formed the main data collection together with data from the innovation centre described in the next sections.

4.1 Data collection

From these projects, and from the innovation centre itself, four primary dataset were collected: six interviews, a workshop facilitated by the researchers, an internal workshop and 486 hours observations.

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We collected data from a number of different sources, including interviews, observations, workshops and archival data from the corporate intranet to corroborate facts. Using four data sources allowed us to triangulate the sources, which improved the robustness of our resulting theory (Jick, 1979). The four primary data sources were:

- 486 hours of observations from the innovation center and six projects
- One workshop organized by the case company
- One workshop organized by the authors
- Six semi-structured interviews with project members from the innovation center.

The archival data we used as secondary data and mainly to corroborate facts such as dates of events. In this manner, we combined real-time data from observations with retrospective data from the other sources, enabling efficient collection of data on multiple projects and maintaining a deep understanding of how events evolve over time (Leonard-Barton, 1990). The characteristics of these methods are described in the following sections.

Observation: All of our observations were undertaken by one researcher who was employed formally in DONG Energy's innovation center to for an industrial PhD. During the study, this researcher spent half of his time at DONG Energy and half of his time at the University (see Table 3). Through this approach, we limited the bias that would have been caused by the researcher becoming native in the company while limiting the bias caused by the participants being aware that they were being observed. To maintain a consistent form of data collection, we documented all observations in field notes using the following template, based on the works of (Blessing & Chakrabarti, 2009; Emerson, Fretz, & Shaw, 1995; Hales, 1987; Lofland, 2006):

1. Metadata – observation no., date, duration, participants and location.
2. Interaction type – chance meeting, dialogue, work session, formal meeting, larger meeting.
3. Topic of the interchange – examples of common topics include the innovation process, decision processes, technologies, regulations, and the future of society.
4. Objective observations – who said what to whom, actions, and order of events with distinctions made between quotations, paraphrasing and summary.

5. Reflections on the usefulness of theory, organizational influences, personal reflections and methodological reflections.
6. Other – most often used for personal reminders of things to do or not to do.

Table 3: Details on observations in DONG Energy

Observation period	621 days
Total length of presence in the company	248 days
Total length of useful observations	64.27 days (482 hours)
Total number of significant interactions	143 points
Maximum length of observations	24 hours
Minimum length of observations	0:30 hours
Average length of observations	3:15 hours

We employed a completely overt observation strategy, explaining the reasons for our researcher's presence to participants whenever a new person was observed. Our explanation of the purpose of the study was "to explore how the company is conducting innovation in energy to help the company reflect on possible improvements". The explanation was scripted to be true, while maintaining hypothesis blindness for the participants and interactions between these participants were followed. A significant interaction was defined as an interaction important enough for the researcher to record it formally in the field notes. During the observations, the researcher would be active in administrative tasks with as little effect on the participants as possible, e.g., writing minutes, summaries and presentation slides. Thus, the role of the researcher was as an observer, providing the deep understanding that comes from daily presence, combined with the less-biased full observation (Patton, 2001). The observations were carried out over 13 quarters, and focus on following activities within the six projects and the innovation center (see Table 4). Using this approach, we collected data from over 100 different participants, recorded in field notes.

Table 4: Details on the data from observations

Period	Hours of Observations	Central Observed Activities	Significant Events	Central Data on Projects
Quarter 1 *2009*	50,25	IC department meetings Seminar on strategic themes Internal relationship mapping Project work	IC is founded, DIA process model IC Pyramid structure	Inbicon, Better place DK, PowerHUB
Quarter 2 *2009*	73,25	IC department meetings Cleantech collaboration with BU Workshops on new design methods R&D seminar "from ideas to reality" Project work	The Etrans project starts Marguerite structure Effects from financial crisis	Etrans, Renesecience, Inbicon, Better place DK, PowerHUB
Quarter 3 *2009*	18,5	IC dept. meetings ETrans kick-off reflection Project work		Etrans, Renescience, Pyroneer, Inbicon, Betterplace DK, PowerHUB
Quarter 4 *2009*	29	IC department meetings Infusion of design methods from etrans Intranet strategy meetings Project work	COP 15 in Copenhagen ~300 people laid off	Etrans, Renescience, Pyroneer, Inbicon, Betterplace DK, PowerHUB
Quarter 5 *2010*	59,5	IC department meetings Collaboration with HR on processes Eflex project started with methods and data from etrans Project work		Etrans, Renescience, Pyroneer, Inbicon, Betterplace DK, PowerHUB
Quarter 6 *2010*	42	IC department meetings Reinventing processes of IC Reigniting the Etrans project Project work	New top manager Strategic basket process IC wheel structure	Etrans, Renescience, Pyroneer, Inbicon, Betterplace DK, PowerHUB
Quarter 7 *2010*	27	IC department meetings Workshop on global innovation leadership Project work		Renescience, Pyroneer, Inbicon, Betterplace DK, PowerHUB
Quarter 8 *2010*	19	IC department meetings Meetings with R&D from BU's Project work		Renescience, Pyroneer, Inbicon, Betterplace DK, PowerHUB
Quarter 9 *2011*	14,5	IC department meetings Project work	Thermal engineering is sold Fukushima accident New funding process	Renescience, Pyroneer, Inbicon, PowerHUB
Quarter 10 *2011*	70	IC department meetings E2G open data sharing created Introduction of virtual collaboration Project work		Renescience, Pyroneer, Inbicon, PowerHUB
Quarter 11 *2011*	40	IC department meetings Foresight collaboration with Siemens Project work	Inbicon in media-storm	Renescience, Pyroneer, Inbicon, PowerHUB
Quarter 12 *2011*	20	IC department meetings IC + BU's research strategy workshop Project work	Betterplace DK in media storm	Renescience, Pyroneer, Inbicon, PowerHUB, Etrans
Quarter 13 *2012*	19	IC department meetings Seminar on innovation process management Project work	Bottom-up stage-gate IC Bubble structure	Renescience, Pyroneer, Inbicon, PowerHUB, Etrans

Workshops: We used two workshops for this study. In workshop 1, all of the participants received a 20-minute presentation in which we presented the research project as "an exploratory study of the innovation process" and gave a short introduction about how innovation may be defined in terms of the successful integration of knowledge from different domains (Tidd & Bessant, 2009). Our presentation was carefully scripted to provide the participants with enough background information to understand the general purpose of the workshop and three tasks while maintaining hypothesis blindness. After the presentation, we split the participants into four groups, each replicating identical tasks. For all three tasks, the participants were given a five minute scripted introduction and handout in the form of a postcard with the main questions (see Table 5, "topics") and a few lines of supplemental information. In addition, we distributed A0 posters with pre-printed empty matrices to all groups. Each task was timed to last 1½ hours and was followed by a five-minute plenary presentation by each group for each task. After these presentations, all of the matrices with post-it notes attached to them were collected as data.

Workshop 2 was arranged by the company itself; thus, the authors exerted no influence on the participants (or the design of the workshop) during the workshop. It began with a 10-minute welcome by the head of the innovation center, followed by a 45-minute lecture from an external consultant that explained an innovation model called the innovation diamond (Ibbotson & Darsø, 2008). The participants were then divided into 10 groups, and they completed two brainstorming exercises that lasted 1½ hours each. During these sessions, participants had to come up with suggestions about how to balance structure and creativity, and they shared ideas on best practices with their group members. To facilitate this process, the consultant supplied an inspirational toolbox with such methods as negative brainstorming (considering how to make the situation worse) and association cards (considering how Elvis and Einstein would have addressed the task), among other methods. After each exercise, suggestions from each group were presented in

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plenum, and the suggestions were collected as data for analysis. In total, we collected 448

suggestions as data for our analysis. The workshops provided information about the employee's

experiences across a wide range of past projects, and all of the statements made by the

informants were validated and/or corrected by the other participants.

Table 5: Details on the data collection workshops

	Workshop 1 Knowledge in Innovation	Workshop 2 Balancing Structure and Creativity
No. of participants	23 people in 4 groups	54 people in 10 groups
Participants	Innovation function at management, project management and specialist level	Innovation function at management, project management and specialist level
Topic(s)	How may knowledge be structured and made accessible for innovation? How may knowledge-sources be identified and activated in innovation? What are the criteria for evaluating the quality of knowledge management methods?	Create ideas for enhancing innovation by balancing structure and creativity.
Duration	7 hours	6 hours
Preparation of participants	20 minute introduction to KM in innovation and 3x5 minutes explanation of tasks.	45 minute lecture on a mental model describing roles of structure and creativity in innovation.
Staging	Research group staged and facilitated	Case company staged, consultant facilitated
Facilitation	Structured around the three topics with prescribed brainstorm approach and discussions in plenum	Open-ended facilitation, with groups choosing their own methods, presentations in plenum.
Collection of data	Produced material, structured by the participants, captured on post-it notes, flipcharts and posters.	Produced unstructured material captured on large post-it notes with explanations
Amount of data	189 suggestions	259 suggestions
Treatment of data	Coding	Coding

Interviews: We conducted six semi-structured interviews that lasted between one and one and a

half hour. Our interview guide was based on the topics identified from innovation and

knowledge management literature and was followed during the interviews, however,

interviewees were allowed to expand on their answers and the interviewer was allowed to probe

further into topics as they arose. The questions spanned the following four categories: 1)

personal networks and their function; 2) the interviewee's understanding of innovation,

knowledge, and decision making; 3) personal narratives related to knowledge flow and decision-

making processes; and 4) experience with methods and tools used for making decisions, innovation support, and knowledge management. The interviewees were all key team members in the innovation projects with close formal bonds to the innovation center. We transcribed all of the interviews and divided them into a total of 619 segments, with a new segment beginning when an interviewee paused between utterances.

4.2   Data analysis

We established our initial coding scheme from a theoretical framework that combined innovation process support and intellectual capital. However, as themes emerged from the data, we added codes, and sub-codes, by moving back and forth between the empirical data and theory. This process resulted in three coding-schemes (knowledge, decision, and foresight) with 20 codes and numerous mutually exclusive sub-codes (see appendix A).

Firstly, we created an initial coding scheme by eliciting codes from applying the knowledge-based view on innovation processes, thus the initial coding scheme corresponds to Eisenhardt's (Eisenhardt, 1989) a priori constructs and Miles & Huberman's (Miles & Huberman, 1994) conceptual framework. The use of an initial coding scheme connected the study closely to existing theory, through the set of basic codes and categories shown in the literature review.

Secondly, we segmented our four data-sets independently and coded each dataset according to the common coding scheme. For all of the data-sets, segments were coded into multiple codes related to knowledge, decision-making and foresight in order to infer the empirical relationships between these constructs in the final analysis (see the full list of codes and definitions in appendix A and coded examples in appendix A1) (Miles & Huberman, 1994).

The data from the workshops were segmented so that each "suggestion" captured during the workshop became a segment. To each segment, contextual data were added such as the question

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or task given to the participants, and the classifications made by the participants during the

workshop (see Table 6).

Table 6: Example of six contextualized and coded data segments from the workshops

Specific suggestion on post-it notes from participants	Skill-upgrading of current employees in business understanding	"Numskull Jack" (Klods Hans) - Be yourself	Best practice transfer from other large companies e.g. Novozymes	Concern-understanding across the concern via e-learning	Upgrade and internally prioritize networks	Concern management sponsorship
Question / task posed to the participant	How can the knowledge domains be structured and made accessible?	Presentation of the Idea diamond and common language for innovation-task: develop ideas for enhancing Innovation	How can the knowledge domains be structured and made accessible?	How can the knowledge domains be structured and made accessible?	How can the knowledge domains be structured and made accessible?	What are the requirements we need to evaluate the methods against? - And how should the requirements be measured?
Mapping of suggestion done by participant	Organisational structure+ Personalisation+ Access to knowledge	Specific situation of using mud as sauce mentioned	Organisational structure+ Personalisation+ access to knowledge	Organisational structure+ Personalisation	Personalisation+ repository, not social network	Requirement, connected to challenge site
Codes	**Sub-Codes (first order concepts)**					
Innovation Phase	All Phases	0	Front-end	All Phases	All Phases	0
Exploitation of knowledge	Dissemination	0	Collecting	Dissemination	Dissemination	0
Exploration of knowledge	Integrating	Experimenting	Integrating	Monitoring	Reflection	0
Barriers for knowledge transfer	Interpretation difference	Pre-conception of knowledge Quality	Accessibility of source	Accessibility of source	Lack of common frame of understanding	Lack of mediation
Novelty of knowledge	Existing	Partly Known / Adapted	New to Firm	New to Org. Unit	New to Firm	0
Knowledge domain	Business model and processes	0	Business model and processes	All	All	All
Knowledge retention strategy	Create internally	Create internally	Get externally, keep	Spread and Keep	Spread and Keep	0

Hereby, the coder was assisted in interpreting the data as correctly as possible, by having an

overview of not just the exact statement but also the context in which the statement was created.

The interviews were all transcribed and divided into a total of 619 segments, with a new segment

beginning when an interviewee paused between utterances. Contextual information was added in

the form of questions from the interview-guide and all interviews were coded as a single dataset.

The observations were segmented and coded in two separate cycles, due to the magnitude of the data-set. In the first cycle, all the field notes were coded in terms of the three codes of intellectual capital and during this process a fourth code (artifactual capital) was added as the three categories from theory were found to be insufficient for covering intellectual capital embedded into artifacts. This process reduced the dataset into 430 segments, each with a large subset of field-notes within. Contextual information was added in form of a timeline with significant events e.g. "the thermal engineering department sold off", corresponding to the timestamps on the 430 segments. The contextual information, as well as the original field-notes, was used for deeper clarification of segments when needed during the coding and interpretation of segments.

Thirdly, we developed the coding scheme further by analyzing the empirical data to verify or reject the initial codes and sub-codes and to create new codes and sub-codes. Recurring themes found in the four data-sets were identified through three primary code identification techniques: Repetitions, cutting and sorting, and similarities and differences, as all these techniques have been proposed to support both rich narratives (interview and observation data), and brief descriptions (workshop data) (Ryan & Bernard, 2003). These techniques are furthermore found to be appropriate for both verbatim data and field notes (Ryan & Bernard, 2003). This combined questioning and further development of the coding-scheme had the benefit of limiting the bias caused by forcing findings into a solely predefined coding scheme (Eisenhardt, 1989).

Fourthly, we checked the reliability and validity of our constructs in two different ways: To test for the reliability of the coding, we used the kappa test developed by (Cohen, 1960), and to control the validity of our constructs, we presented them to the head of the innovation center. All of our data were coded by one person, hence we checked the reliability of the with a second coder by applying (Cohen, 1960)'s Kappa test. We gave a second coder the definitions of the

codes together with an example of each code. Then we asked the second coder to code a sample

of 20 segments from each workshop, 20 segments from the interviews and 20 segments from the

observations. Based on the comparison of the 80 lines of coded samples with the original coded

lines, we calculated the frequency of agreement between the two coders while calibrating for the

frequency expected to occur by chance. Finally, we compared the results to those found in

(Bakeman & Gottman, 1997) to draw the following conclusions: 0.4 – 0.6 was considered fair,

0.6-0.75 considered good, and 0.75 – 1.0 considered excellent.

Table 7: Inter-coder reliability test

Coded Dataset	κ	Reliability
Workshop I	0,757	Excellent
Workshop II	0,671	Good
Interviews	0,600	Good/Fair
Observations	0,81	Excellent
Across Datasets	0,74	Good

We found that the Kappa values within and across all four data sets were satisfactory as there

was generally good to excellent reliability, indicating reliable coding and little bias due to the

coder. We found that the most reliable coding, categorized as *excellent*, was that of the

observations, whereas the interviews were the least reliable, with a score of *good to fair*. From

this comparison, we consider the results from the analysis reliable.

Finally, the analysis of the four datasets was brought together by searching for patterns and

differences across all four datasets through identifying co-occurrences of codes in data-segments.

Also, within-set analysis was done on the longitudinal data-set from the observations in order to

identify the emergence of patterns over time. Finally, the identified patterns were explaining by

going back to the data segments in which they occur, and for the observations by going all the

way back to the field-notes.

4.3 Analysis of results from coding scheme

Guided by our research question and conceptual framework, we created an analytical framework in the form of an impact-matrix, showing how each category of dynamic capabilities support the innovation process (see Table 8). From the empirical data, we added a fourth type of intellectual capital, artifactual capital, as it proved to be essential in explaining the feedback loops from innovation back to changes in processes, knowledge and networks covered by the three capitals identified in the literature. Our definition of artifactual capital extents the intellectual capital theory and is articulated along in line with the three existing intellectual capital definitions by (Subramaniam & Youndt, 2005). We define a*rtifactual capital* as "the codified knowledge that is embedded in artifacts deliberately produced by the firm, which is available through and utilized in interactions among individuals and artifacts". Finally, we populated this matrix using the thematic coding process. Thus, our study is consistent with the argument by (Barnett & Carroll, 1995) that studies of change must simultaneously focus on content (what) and processes (how) using theoretically motivated variables.

Table 8: Matrix for cross-tabulating dynamic capabilities and innovation support

	How (dynamic capability category)			
What	**Human Capital**	**Social Capital**	**Organizational Capital**	**Artifactual Capital**
Knowledge				
Decision				
Foresight				

5 Discussion of Findings

In this section, we first describe the mixed-mode innovation process at DONG Energy with the aim of confirming and extending our theoretical understanding of support of the process. Second, we explore in detail how knowledge, decision and foresight support is created by innovation teams during their daily work. Finally, we discuss the how dynamic capabilities develop and

evolve to support innovation (Charts for pattern-analysis from the observations backing the analysis up are supplied in appendix B)

5.1   Confirmation and elaboration on the messy innovation process

Through our analysis of the innovation center data, we identified four large distinct changes to innovation process management models, as shown in Table 4 "significant events". These models were developed and implemented into the innovation center, using widely varying methods. The first was developed with a global top 5 university, the second was developed with an internationally renowned consultancy, the third was developed internally in a top-down manner, and the last was developed internally in a bottom-up manner, driven by a new employee with consulting experience. However, our data revealed that none of the process models were ever considered to be of much help by innovators, who struggled to associate their particular projects with the linear models.

> *It is very challenging to develop a "best practice" innovation model, since we don't have one single project done in this new organization yet.* [Quote, innovation team member]
>
> *Much confusion as to where innovation projects and activities should be placed in the model is observed* [repeated observation from innovation center meetings]

The managers had a more positive picture of the process models and emphasized how valuable they were for internal communication purposes and portfolio overviews. Therefore, we compared the process models to the activities performed by the innovators to understand this discrepancy. Compared to the activities in the innovation teams, the process models represented adaptations to changing conditions but were also behind the very problems at which they were aimed. One example is the introduction of *the strategic basket model* in quarter 6. This model was intended to break down exploration into further detail to facilitate communicating progress upwards. However, by the time the model was introduced, the issue had been replaced by

another more pressing matter i.e. freeing up innovation capacity to use the budget allocated to initiating new exploratory activities. Therefore, the focus had shifted toward exploitative activities that were necessary to prepare promising exploratory projects for transfer to the business units. Our analysis showed that the last model, the bottom up stage-gate, was considered the best model of the four for two main reasons. First, it was intended to support exploitative activities, which, for the first time, were synchronized with the need of the business units to explore new products (notably, what the innovation center considered exploitation was considered exploration by the BU). Second, the bottom-up development approach facilitated collaborative reflection on the innovation processes, which led to several improvements that were not directly related to the process model itself but which had emerged during the process of creating it, which is consistent with (Smith et al., 2010). From the empirical data, we created the representation of the innovation process observed in Table 9.

Table 9: Emergent innovation process created from data

Activity	Outcome	Innovation support	Examples of supportive data
Acquiring knowledge through creating and absorbing it.	Knowledge-streams and temporary knowledge pools	Knowledge	Transparency is needed in our corporate resources - who knows what? [workshop] The innovation centre realizes that they are too heavy on technical competencies. [Observation]
Activating of knowledge	Creation of innovations	Knowledge	Insight into battery control technology has been acquired through buying Lithium Balance, but they are difficult to create integrated business on [Observation]
Formal decision making	Formal recognition of innovations	Decision making	Opportunism and strategic directions compete to redefine the existing corporate decision culture which has become obsolete due to a shift away from exploiting thermal plants, and into integration of renewable energy [Observation]
Mobilizing support	Self-sustaining innovation with justification-ability	Foresight	Collaboration with Siemens: innovation center meets the equivalent department in Siemens to create joint "pictures of the future" [Observation]

The model in Table 9 is organized as the process most frequently progressed within the company. It ends with the innovation becoming self-sustaining and becoming the justification for new, similar innovations. This process was observed to occur despite the fact that none of the innovations created positive revenue during the observation period. The activity/outcome columns show the causal relationship that we identified in the data between the activities and outcomes, but the sets were observed to occur in any order and the process may start at any level of rows one through four. This messy aspect of the model confirms the theoretical non-linear model that we derived from the literature and explains why the innovators could not fit their projects within any of the four different sequential process management models introduced. We further compared the three types of innovation support derived from the literature to the data underlying the model in search of new types of innovation support that were not previously covered by the categories. No new categories were identified, and thus, we consider our categories valid in our context.

Proposition 1: The multi-mode innovation process has the following two characteristics: 1) it follows a messy structure to the extent that process management tools that assume a linear flow will fail to provide team-level support, and 2) it can be effectively supported by detaching the three primary support functions of knowledge, decision, and foresight from the innovation process management models.

5.2   Knowledge Support

In the knowledge code, we identified the following seven subcategories of innovation support: *Stability, Exploitation, Exploration, Barriers, Novelty, Domain,* and *Retention.* Two of the sub-categories are directly associated with activities in which knowledge is explored and exploited.

We found that balancing exploration and exploitation is essential for innovation performance, even in units expected to be exploratory because they also experienced local punctuated equilibriums. Thus, we observed punctuated equilibrium and ambidexterity to co-exist. Balancing the exploration and exploitation departments was found to be closely related to strong bonds between the two in terms of knowledge overlaps and social ties between individuals.

> *Social bonding becomes more and more important - projects are more stable than the line organization* [Workshop 2]

We identified the following two examples in our analysis: 1) a project that was exploring how the oil refining industry could be disrupted by using newly developed biotechnology chose to develop a business model that combined exploitation of the stable but low-margin market for electricity with the volatile but high-margin market for crude oil, and 2) a project that explored different business models for electric vehicle services by simultaneously using them in the balancing and spot markets for electricity and in direct sales to consumers. Both projects naturally required in-depth knowledge on the emerging and potentially disruptive technology. However, the teams also required strong bonds with the business units and insight into their existing markets and technologies to draw on the knowledge of the system that is being disrupted and to support the maturation of the disruptive technology.

The process that we observed (see Figure 2) is one of a double-punctuated equilibrium, with the innovation center in a base state of disequilibrium, punctuated by short phases of equilibrium, which typically arrive when their capacity is fully utilized. Conversely, the business units have a base state of equilibrium, punctuated by short phases of disequilibrium that are typically initiated by pressure from top management to innovate.
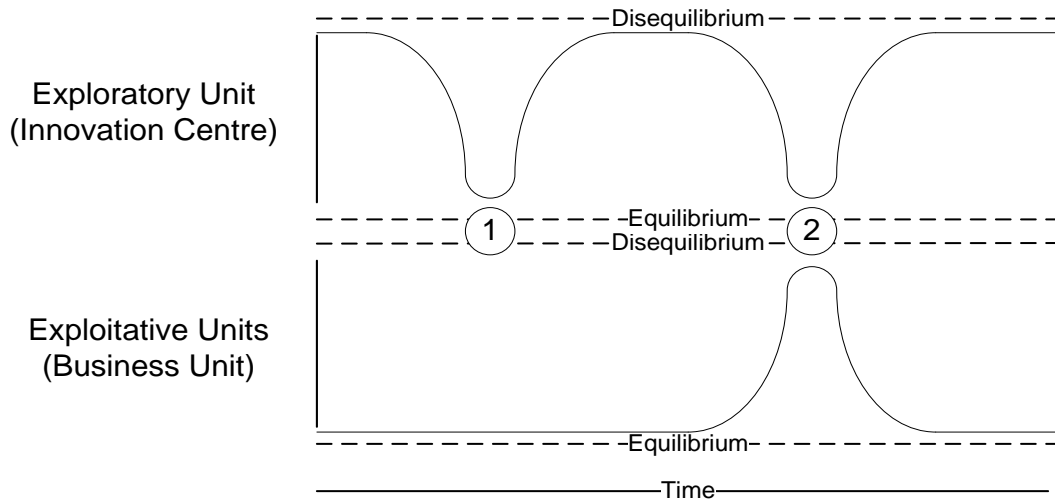
Figure 2: Synchronizing punctuated equilibrium in an ambidextrous organization

Thus, innovations that mature enough to create a state of equilibrium in the innovation center represent disequilibrium when introduced into the business unit. We found the key process indicator for a successful transition between the innovation center and business unit to be synchronization of the innovation center entering equilibrium with business units entering disequilibrium (see, "2" in Figure 2). The task for managers thus becomes keeping the waves of the two systems synchronized and maintaining the framework for securing an appropriate combination of capabilities for exploration and exploitation in the ambidextrous team (the innovation center) and business units. The task for the innovation team becomes mastering both sets of capabilities while remaining aware when they are in exploratory and/or exploitative mode; this task must be based on sensibilities not dictated by process management systems.

Table 10
Evidence and codes for knowledge

Codes	Description	Sub-codes (mutually exclusive)	Examples of supportive data
Stability	Stability of the knowledge which the observed activities pertain to. The categorisation range from completely stable facts to highly dynamic knowledge in constant flux.	Dynamic, Temporary static, Static	A need for being able to model dynamic market-effects leads to a new PhD with Jack as supervisor [Observation] Creation of pictures of the future [Observation]
Exploitation	Activities concerned with exploiting existing knowledge, through teaching, mixing teams, capturing information in databases etc.	Concentration, Dissemination, Externalising, Collecting, Codified Dissemination, Personal Dissemination	Skill-upgrading of current employees in business understanding [Workshop] We-culture instead of Me-culture [Workshop]
Exploration	Activities aimed directly at managing knowledge along a new trajectory, as well as integration of knowledge from different domains in order to create shifts in technological trajectory.	Reflection, Monitoring, Experimenting, Integrating	"Angry old men" - Relations through projects [Workshop] Upgrade tools for idea management [Workshop]
Barriers	Types of issues with transferring knowledge directly from person to person as well as in codified form through reports, guidelines, databases, emails etc. Transfer of tacit, implicit and explicit knowledge-types all appear within this code.	Pre-conception of knowledge quality, Ease of access, Deliberate restricted access, Mediation, Cause for interaction, Lack of common frame of understanding, Accessibility of source, Knowledge level distance, Interpretation difference	Common language between us and the business units [Workshop] Stop rejecting inputs and ideas from others, just because we don't understand them and are too busy to bother [Workshop] Diversity creates more innovation but requires openness - learn to listen in this situation [Workshop]
Domain	Domain of knowledge which the observed activities pertain to. The classification is based on what the knowledge is about and represents an extension to distinguishing between market and technology knowledge.	Business model and processes, Funding, Internal alliance, External alliance, Regulatory environment, User insights, Market dynamics, Technical characteristics, Energy-system synergies, Energy resource reliance, All domains	We need an overview of how the landscape of possible business models in the value network looks – who should be connected how? [qt] We need a professional dedicated regulatory innovation department [workshop] For a concept to be chosen, it helps significantly if it is embedded in either an app or in the cloud – the buzz rules [Interview]
Novelty	Novelty level of the particular knowledge that is handled by the informants. The scale ranges from knowledge completely new to the world, down to common knowledge that is reused in a different context.	New to world, New to firm, new to organizational unit, partly known / adapted, Existing	Business Unit 1 is under a lot of pressure and need to innovate; Etrans, Virtual Power Plant and Better Place are providing them with that. [Observation]
Retention	Describes the strategy followed in order to purposefully keep or discard the knowledge in use. The categorization ranges from complete absence of deliberate learning to internal creation of knowledge.	Spread and keep, Create internally & keep, Get externally & keep, Consult external source	Knowledge has to be spread in a wider network: Design camps, Road show and conferences will be done. [Observation]

Based on our analysis of the *stability* of knowledge in the innovation function over time, we identified a gradual shift in focus from an even distribution between focusing on dynamic and temporary static knowledge at the beginning of the study to focusing approximately 80 % on temporary static knowledge toward the end of the study, with the remaining 20 % given to dynamic knowledge and no attention given to static knowledge. We found that the shift in focus was caused by a shift toward exploitation and transfer of innovation projects to the business units, making it beneficial to create temporarily static pictures of the future and thereby easing communication with the business units about an uncertain future.

In the *exploitation* code, we found evidence that supported this finding, demonstrating that exploitative activities did indeed become increasingly frequent toward the end of the study. Central activities, which were initially distributed across all of the codes, became progressively focused on collecting and disseminating information, including packaging and shipping knowledge about innovations to business units and spin-off companies, as described by the informants.

Within the *exploration* code, we were surprised to learn that experimentation and integration activities were consistently in anti-phase; the creation of new knowledge through experimentation was followed by an integration phase. This finding was further emphasized by a macro-trend in which integrative activities increased quarter by quarter at the expense of experimentation. The waves were essential for the creative process because the inputs created during experimentation provided material for subsequent integrative activities and the integration process provided a deeper understanding of the problem, thereby driving the direction in which the next phase of experimentation should proceed. On the aggregate level, we found that integrating knowledge required the highest level of support in this code; off-line experimentation

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activity rarely required managerial intervention and was most productive when it was conducted within autonomous teams. Managerial resources were better used to generate structures and processes for integrating the knowledge created by the specialist team than to set the direction of upcoming exploration.

> *Exchange ideas, where the idea is taken further by a new person with a novel view on i*t [Workshop 2]

The greatest *barrier* to knowledge transfer was the lack of a common frame of understanding between an increasing number of knowledge domains and between business units. We found the need for a common frame of understanding to be equally important across exploration, exploitation and the transition between them. During exploration, this frame is necessary for integrating knowledge domains that are new to the company. In exploitation, it is used to efficiently execute tasks when related fields are collaborating on improving an innovation. In transitions, the framework is required to efficiently transfer innovations that are on the fringe of their current knowledge to the business unit. These findings are consistent with those of (Ancona & Caldwell, 1992) with respect to the high-impact boundary spanning has on task performance.

In our analysis, we identified 10 distinct *knowledge domains*. When we analyzed these domains longitudinally, we found that the holistic view that existed across knowledge domains in the beginning was replaced with an increased focus on single domains, particularly as the innovation activities became less exploratory. Peaks in holistic attention to knowledge domains were correlated with peaks in the waves of knowledge integration. Increasing attention to regulatory innovation was observed until quarter five, decreasing significantly in quarter six when the innovation center was split from regulatory affairs; it remained insignificant until quarter twelve, when the departments merged again. This trajectory emphasizes the close connection between regulatory knowledge and innovation in the company. Over all of the innovation projects,

regulatory innovation was observed to be an essential design dimension that was completely integrated with the technological solutions in question.

In our analysis of knowledge domains represented in the innovation teams, we identified a need for different knowledge profiles over time that correlated to the team's degree of exploration or exploitation activities. During exploration, innovations with the greatest novelty and perceived potential came from "Renaissance teams" that covered every potentially relevant domain at least to a certain extent. Not all domains were explored in full depth, but they were explored in sufficient detail to determine whether they presented potential problems, solutions or neither. During exploitation, we observed that the holistic concepts created by the renaissance teams' approach eased the mobilization of support from the business units as any given sub-concept or choice had many different rationales, facilitating the "sell" to specialists in essential domains who are quickly mobilized.

> *When BU's* (business units) *focus on development, e.g. wind, IC* (innovation center) *has to pick up what is left outside the focus area – holism* [Observation]

Our analysis of the *novelty* of knowledge revealed a shift over time from knowledge that was new-to-the-firm to knowledge that was new-to-the-organizational-unit, which is consistent with the shift toward transition and exploitation that was identified above. This observation confirms our finding that what is considered exploration by one department may be considered exploitation by another department.

From our code of knowledge *retention*, we found a shift from absorbing knowledge from external sources during the early period of strong exploratory activities and knowledge novelty to the internal creation of knowledge during the focus on exploitation and the transfer of knowledge that is new to the business unit. In this code, we observed the introduction of user-

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driven innovation methodologies within the company. Introducing and retaining novel procedural knowledge were highly reliant on the relevance of this knowledge to a concrete innovation project. When user-driven innovation knowledge from Etrans (exploratory) was first transferred to the business unit, it failed to generate any interest. Subsequently, an internal project was established with the aim of creating innovative energy services for electric vehicles for end-consumers, and support was mobilized for learning this new methodology through that channel. We consequently observed that artifactual capital either preceded or ran concurrently with the creation of the other three intellectual capital streams.

> *Our main issue with selling technologies to BU's is that we are arguing for a business in a system that does not yet exist* [observation]
>
> 003*: Technical products with high knowledge content requires years of educating the deciders before any real decision making is done* [observation]

Proposition 2: The five central mechanisms for knowledge support are: 1) exploitative process knowledge with close bonds to business units are central to continued high exploratory performance from the exploratory team; 2) the creation of renaissance teams working in cycles of experimentation and integration improves the likelihood of creating concepts that are both novel and realistic; 3) linking active mediation and creation of common frames of reference to exploration and exploitation is likely to improve boundary spanning between knowledge domains; 4) new procedural knowledge is likely to be adopted faster if it is tied to technological innovation; and 5) the exploratory and exploitative phases in the ambidextrous organization are likely to be able to be synchronized via innovation portfolio management.

5.3   Decision Support

During our analysis of the decision support, we identified the following four central

subcategories of specific capabilities that support innovation: *practices, decision-maker*

behavior, centralization, and *decision object behavior.* We found that decisions became

increasingly explicit over time as the innovation function made sense of innovation ideas and

their particular contexts, leading ultimately to a set of formally recognized innovations generated

by the process, as illustrated in the following process description:

1. An employee has an idea for an innovation project.
2. He addresses the director of the IC to obtain resources and other support.
3. The director likes the idea, despite not understanding it completely – he considers the employee to be knowledgeable, so he trusts that the idea is solid.
4. The director sends the employee to experts in the field to further discuss the idea and to determine whether they approve of his idea.
5. These specialists join in improving the idea, sending the employee to more specific specialists as well as to business unit managers who might be interested in exploiting the idea should it become a reality.
6. After the extensive development that the idea has been through to this point, the employee returns to the director and presents the current state of the idea and the support for it.
7. The director meets with the specialists and managers to build a consensus regarding what further actions are appropriate.

We observed that the long sense-making process that preceded any formalized decision makes

the formal decision a less significant event because the outcome is almost predictable. Our

findings are supported by Weick's (2004) concept of a shift in management style from decision

making to sense making, implying a transition from static analytical decision methods to

transient methods that are useful for a time (Boland & Collopy, 2004).

> *Hmm +++ and then of course than there is a MORE INFORMAL knowledge gathering and, and the attitude and + hmm, and process of having of network and I think a lot of decisions and a lot of the information is gathered through the network and knowing people and + having access to the right ones. Hmm so you need to understand that game and and play that game, to be able also to facilitate your role as + a project manager, because not ALL the things are, are decided through the project management, process + hmm but also decided outside that, or + the opinion or the people that needs to be involved or the people that needs to be +++ hmm hmm affected + for making the right decisions ARE done through the network or informal network.* [Interview]

Table 11
Evidence and codes for decision

Codes	Description	Sub-codes (mutually exclusive)	Examples of supportive data
Practices	Types of practices for making decisions. The classification is based on descriptions of the underlying process of the decision i.e. whether the best alternative for a problem is chosen or if the decision pertains to single isolated item, as well as how criteria are generated.	External authority, Network support, Core capability utilization, Business model alignment, Fit requirements, Fit foresight, Best requirements fit, Best foresight fit	pilot->test->evaluation->decision would be a nice approach instead of the politics [Workshop] Knowledge on new technologies require special internal political processes, we learned that from heat pumps [Interview]
Decision-maker behavior	Behavior of the decision maker, which is considered as a role, thus it can be taken on by either an individual or a group of people. The code is defined along two dimensions: explicit vs. implicit and social vs. personal.	Explicit personal, Explicit social, Implicit personal, Implicit social	Make the down-stream decision board into personas e.g. "what would CEO do here?"[Workshop] Larger transparency in the company regarding rationale behind management decisions [Workshop]
Centralization	Degree of centralization of the decisions observed. Also, this code covers whether activities or arguments in discussions supports centralized or more distributed decision making. The categorization range from completely central decisions to decisions taken closest possibly to the operational level.	Centralized, Intermediate, De-centralized	Fast decision structure is strongly needed for our innovation - A spaghetti organization. [Workshop] We see a gradual centralization, taking over more and more of the innovation efforts from the business units, to enable a strategic directed effort, with sourcing of competencies from the innovation centre into the business units. [Observation]
Object behavior	Behavior of the object of the decision, as it is perceived through the descriptions of the decision makers (individuals or teams). The categorization covers a continuum from the completely irrational to the completely rational.	Irrational, Hybrid, Rational,	Vast amounts of photovoltaic cells inserted the German system, tells DONG Energy what will happen in the Danish future: demand beyond the meter will go down [Observation] …we need to create a large 2050 scenario, national + international, for justification and then roadmaps for all the avenues. [Observation]

Our analysis showed that the approach to selecting new innovations was dominated by the following three distinct *practices*: the fit with foresight approach, business model alignment, and core capability utilization. The visionary approach to decision making based on fit with current foresight dominated in the early exploratory quarters. During the more exploitation-focused later quarters, decision making based on alignment with business models became increasingly dominant. From quarters 8 - 10, when the focus shifted from exploration to exploitation, we observed a temporary peak in the emphasis on core competencies as the driver for decision making; however, it never became a dominant practice but remained a secondary concern. In our analysis of the change from foresight model to business model, we noted that projects that had been decided upon because of their visionary and potentially disruptive character would ultimately force the focus more to rethinking the core business models of the business units. This outcome was achieved because the exploratory teams were free to try out alternative business models, which, if successful, could be transferred together with the new technology into the business unit.

> *Maybe the first line has to be: "Here is the money". Because, if you can make a business model where you can show there is the number of 1 000 000 Dkk you can earn in the next 10 years, that's the BASIC driver.* [Interview]

In our analysis of *decision-maker behavior*, we observed that across all quarters, decisions regarding innovations were not typically made by individuals but instead by groups of individuals. The informants considered "decision by committee" to be an appropriate tool for decision making under radical uncertainty. However, this behavior sometimes created a decision vacuum because when a person is not forced to make a personal decision, the "hedge" position is likely to be sending the problem further out within the system of specialists, as in our example. Therefore, innovators developed surprisingly strong network management skills – or skill at

what (Akrich, Callon, & Latour, 2002a) referred to as the art of *interessement*. Throughout the study, the most dominant *decision-maker behavior* was explicit social decisions, and this dominance became significantly stronger toward the end of the study. In our analysis of this increase, we identified two central drivers. First, innovators made an effort to formalize their process governance. Second, as the innovation projects received increased attention and participation from the business units, the network of people involved became too large for implicit social decision making.

Contrary to our expectations, the analysis of *centralization* suggests that social decision practices are not correlated with decentralized decision making. Although the decisions are made by a committee, our analysis reveals a highly centralized decision structure relative to what (Hofstede, 1997) found to be typical in Danish culture. Power was deliberately pulled increasingly close to the group level and taken away from the business units to create a more coherent innovation strategy and to drive the company toward a new trajectory. Centralization of decision power was most tangibly observed in control over budgets, in which significant funds were transferred from local control by the business units to central control by the executive support group. However, within the innovation center, the flat structure was maintained because it was considered a prerequisite for fostering innovation.

Our code *object behavior* describes whether the object of the decision is perceived by the decision maker to behave rationally, irrationally or both. In our case, the objects include concepts, projects, technologies, and contexts. How an idea (e.g., an idea for locally produced energy integration) might be perceived to fit within the business and energy systems and therefore be worth pursuing is a good conceptual example to illustrate this type of behavior. The idea was initially perceived differently by different individuals during the early quarters, which

can be observed in the data in the equal distribution between the three perceived *object*

behaviors. These data indicate that none of the innovators had truly made up their minds about

whether the extended energy system was rationally definable and therefore predictable in its

behavior. This phase was followed by a more homogenous one in which the system's behavior

was primarily considered to be hybrid. The perception of the systems as hybrid prevailed until

the end; however, the view of the system as irrational, which suggests that the system is

completely unpredictable, regained some momentum in the last two quarters. Here, we observed

two separate effects. First, a consensus was built throughout the quarters about objects of the

decision exhibiting hybrid behavior rather than rational behavior, which is explained as a

struggle between whether the innovators perceive their innovations to be technical systems or

socio-technical systems. Second, the introduction of user-driven methodologies supported the

hybrid view. However, as attempts to create innovations for the end-user segment failed based on

analyses performed using these methods, a new surge in the perception of the decision object as

irrational and unpredictable gained momentum.

> 002: *The UDI (user driven innovation) approach used in the Etrans project lead to some
> disintegrated narrow solutions with little technological and business content*
> [observation]

Proposition 3: 1) Decisions taken socially on the specialist level with an equal weight on

deterministic systems analysis and methodical constructivist foresight are more likely to yield

informed decisions for the different modes of innovation than decisions at management level

based on pure analytics. 2) The decisions in 1) are unlikely to occur without specific tool

support.

5.4   Foresight Support

In our analysis, foresight was found to be an important guide for both decision making and sense making when encountering situations of radical uncertainty in which explicit strategic roadmaps failed to apply. This happens because the socio-technical system receiving the innovation is not yet stable, or will be destabilized by the disruption. When stability later on starts to occur, it will essentially be too late to influence the system in any major way. These findings are supported by (Weick, 2012), who suggested that in an unknowable and unpredictable world, a compass is a better guide than a map because the latter is outdated before it is put to use. In our analysis of the foresight support, we identified the following eight central subcategories of specific capabilities that support innovation in this system: *source temporality, source type, model paradigm, future temporality, formal acceptance, relationship, methodology, and role.*

The code *source temporality* refers to the time period that the data used to generate the foresight are from, in terms of the past, present, and future. Future data can be gathered through simulations, such as war games that generate data about a variety of plausible futures before they occur in reality. We observed three waves of data in our study. The first wave lasted for four quarters and rapidly changed between focusing on the present context and future data. The second wave lasted for five quarters and involved concurrent and equal use of present and future data. The third wave lasted for four quarters and was heavily dominated by future data. The limited reliance on historical data poses a challenge as analytical tools, such as mathematical modeling, which are used to forecast everything from sales to consumer moods, cannot be used to predict a future that does not in some way mimic the past. However, as these are the only tools available, there is a conflict between human sense making and decision making based on mathematically analytical methods. All of the informants are aware that their analytics are fallible in this context, but the numbers still have great persuasive powers, creating a conflict between sense making and decision making.

> 022: *Needs of the technical system drive everything: after large UDI projects, we end up with the exact same products on the shelf as before*. [observation]

Table 12
Evidence and codes for foresight

Codes	Description	Sub-codes (mutually exclusive)	Examples of supportive data
Source temporality	Temporality of the data the foresight model is build upon. The categorization covers data collected from the past through to the future.	Past experience, Current context, Future contexts	IC hosts a conference on future scenarios for reusing knowledge on gas and the existing gas infrastructure in a sustainable system in the future. [Observation]
Source type	Type of data source for creating the foresight model. The classification is two dimensional and covers internal vs. external and political vs. specialist as sources.	Internal political, Internal specialist, External political, External specialist	Access to specialists in white spots are challenging, we don't know what happens on local wind turbines and sun.[Observation]
Model paradigm	Paradigm of the foresight model as it is perceived through the descriptions of the individuals or teams creating and/or using it. The categorization is binary: either there are multiple equally plausible futures or one deterministic future that can be extrapolated from past data.	Determinist, Constructivist	Vast amounts of photovoltaic cells inserted the German system, tells DE what will happen in the Danish future: demand beyond the meter will go down [Observation]
Future temporality	Temporality of the foresight model, in terms of whether how far ahead of today it reaches. The classification covers a continuum from the near future to the far future.	Near future, Mid future, Far future	…we need to create a large 2050 scenario, national + international, for justification and then roadmaps for all the avenues. [Observation]
Formal acceptance	The degree to which the perception of the future is accepted formally by the organization. The classification goes from the extreme of a personally held perception by a single individual, to a codified official picture of the future.	Personal, Social, Codified	The key lesson learned from Eflex was deeper shared knowledge on what the energy system can expect users to help with, if they are given every smart solution possible. [Observation]
Relationship	Relationship the individuals or groups have towards a specific picture of the future. The classification is two-dimensional based on whether positive vs. negative perceptions and whether the perception causes actions or not.	Normative, Desired, Indifferent, Feared, Threatened	Core competencies in the future becomes modeling of the future, where financial sectors and physical sectors merge, to hedge the risk for a new financial meltdown [Observation]
Methodology	The approach by which the foresight model is made. The classification is binary: either a formal method e.g. Delphi or forecast algorithms are used to create the model or it is made through an implicit emergent approach.	Formal method, Emergent approach	IC decides to join Energy2Gether – a system for sharing energy data and predictive models between all actors in the energy sector [Observation]
Role	Role of the picture of the future in relation to concepts or projects. The categorization is based on whether the picture is used to contest, initiate or set a strategy for projects.	Strategist, Initiator, Opponent	When BU's focus on development, e.g. wind, IC has to challenge them by picking up what is left outside the focus area [Observation]

Our analysis of *source type* revealed a similar three-wave pattern, but it preceded the temporality pattern by one quarter. The first wave was dominated by rapid shifts between external and internal specialists. The second wave was highly influenced by political forces of internal and external origin. The last wave was dominated by internal specialists. We found that the reasons for these shifts have little relation to the transitions between exploration and exploitation. These waves were affected by significant external events. In the first wave of shifts between internal and external specialists, the innovation center had recently been started and was searching for a fact-based narrative to provide a rationale for the transition to sustainability, ultimately deciding to use a description of the fossil-fuel industry as having experienced a 200-year bubble that was about to burst. In the middle wave, Denmark hosted the COP15 meeting in Copenhagen, and the political environment became a strong source of expectations regarding the future. Near the end of the study, conflict in the media about large innovation projects, such as Inbicon, made internal specialists the preferred source of the company's predictions, as they were expected to provide rational arguments for how these projects could have a role in the future that would make them worth the current conflict.

Our analysis of the *model paradigm* indicated that the dominant perception of the future across all quarters was constructivist, which led to the further suggestion that there are multiple plausible futures rather than a single certain future that could theoretically be foretold with sufficient data. This finding is consistent with employees' limited reliance on historical data to assess the future but is not consistent with their extensive use of mathematical analytics for decision making.

Regarding the code *future temporality*, we were surprised to find that most of the activities were targeted toward the near future (0-3 years) across all quarters. The far future (over 8 years) dominated in quarters two and four and became secondary during the second half of the study, which is consistent with the shift from exploration to exploitation. The mid-future (3-8 years) was surprisingly not emphasized in any of the quarters. The strong focus on short-term activities was a

function of the need to legitimize the new focus of innovators and the creation of the innovation center. Significant resources had been diverted from the business units, and these units were very powerful. Therefore, the innovation center had to ensure that it could rapidly prove to the business units that it was capable of creating something tangible. The limited activity focused on the mid-future is also a function of the inability of the prediction methods used to create a useful mid-term picture. In analyses of the far future, it is helpful to consider macro-trends, such as the scarcity of oil and population growth. In analyses of the near future, data can be reliably extrapolated from the current context because disruptive changes will have little effect during the short term. In constructing a useful mid-term picture, we found two central challenges. First, the analysts could no longer assume their extrapolations to be accurate because the multitude of unknown factors begins to become significant beyond three years. Second, the mid-term future is not far enough away for these factors to cancel one another out and aggregate into a macro trend. Consequently, the mid-term future was the hardest to make any meaningful foresights for, primarily because of the lack of methodical support.

The importance of support for the mid-term future was surprisingly not reflected in the existence of concepts for midterm use but was reflected in the internal competition for resources, where mid-term concepts were found to be under-prioritized in competition with long-term and short-term concepts.

> *005: We have cut power engineering loose and lost a lot of competencies in the gas grid development, but now we need similar again as the gas grid is a promising storage.* [observation]

An example of such a mid-term concept is the conversion of thermal power plants from the combustion of fossil fuels to the combustion of a wide range of biomass-based fuels. This technology concept created a temporarily profitable business while allowing DONG Energy to build up its know-how on sourcing and handling of several new types of biomass. In a later long-term project, this knowledge is expected to become a competitive advantage for disrupting the oil-

refining industry. A similar process was observed in previous empirical studies innovations by (Akrich et al., 2002a; Akrich, Callon, & Latour, 2002b), in which the researchers stated that new innovations are sustained by previous innovations for a substantial period of time rather than becoming self-sustaining overnight. In our case, we found the disruptive change to occur slowly enough to create a temporary market for mid-term technological innovations, but the tools to support it appear to be lacking.

In our analysis of the *formal acceptance* of foresight, we observed three cycles of acceptance, moving between consolidations of foresight through codification and challenging the foresight through extensive social debating. In the first two quarters, the foresight was primarily embedded into the social network and frequently challenged. Following this period, until quarter nine, a period of consolidating the foresight into fewer codified scenarios dominated, and strategies for acting on these scenarios were developed. From quarter nine onwards, the foresights turned social again, and new debates challenged written assumptions, initiated by a surge in personal foresights in quarter nine, meaning that people had increasingly begun to create their own pictures of the future. We found that the constant challenging of assumptions inherent in the socially embedded foresights improved the accuracy of both the foresight and how people interpreted this foresight. Conversely, we found the codified consolidation to facilitate more action in terms of the concrete innovation activities started. From this observation, we conclude that the shifts are important for driving concrete actions in the most accurate direction.

Our analysis of the *relationship* code indicated that the increasing diversity of foresights and the constant challenges occurring from quarter 9 and onwards induced a feeling of indifference towards the future in the innovation teams. In the earlier phases, we observed a high degree of normative relationships to foresights, indicating that people were actively trying to shape the future in the given direction. This finding emphasizes the need for innovation managers to develop a structured

approach to support the shifts between challenging and consolidating foresight to limit the duration of assumptions being challenged and to prevent indifference from spreading.

Our binary analysis of the *methodology* used to generate predictions shows a gradual shift from the methodical production of foresight to an emergent approach until quarter ten. Beginning in quarter ten, the methodical approach became increasingly dominant again, driven by a renewed focus on predictive analytical models.

Finally, our analysis found that during innovation, foresight shifted between the three *roles* of strategist, initiator and opponent throughout the three waves. At first, all three roles appeared equally frequently, then the roles of initiator and strategist became dominant, and finally, the role of strategist became dominant. The apparent reason for this shift was that the exploratory projects had to ensure the legitimacy of their approach at the outset but later emphasized their strategic role as they moved toward the exploitation phase, in which they were required to set trajectories for existing projects and new ideas.

Proposition 4: 1) A clear picture of the point on the continuum between exploration and exploitation where an exploratory project, combined with a clear role of foresight, is likely to improve the speed at which such project can be absorbed into a business unit for exploitation. 2) Methods for creating foresights and innovations for the mid-future are likely to help a potential disruption. 3) Deliberate teaching of a foundation for understanding foresights correctly for the entire innovation team is likely to improve the speed and accuracy at which it adapts to new conditions.

5.5 Mechanisms for connecting intellectual capital streams with innovation support

Our propositions for supporting disruptive innovation are specific mechanisms in which intellectual capital is created with the goal of supporting one of the three innovation support functions. As an overview, we created an impact matrix with intellectual capital as the independent variable, the three categories of support for disruptive innovation as the dependent variables, and the observed mechanisms as the mediators (see Table 13).

Table 13: Impact matrix showing how dynamic capabilities within the four categories of intellectual capital support innovation.

	Dynamic capabilities in a knowledge resource perspective: How may dynamic adaption of knowledge-resources and routines be supported			
Output type:	**Human Capital**	**Social Capital**	**Organizational Capital**	**Artifactual Capital**
Knowledge • Resources • Routines	**Proposition 2.2** the creation of renaissance teams working in cycles of experimentation and integration improves the likelihood of creating concepts that are both novel and realistic. Illustrative quote: *"001: A team with all skills needed is impossible to create when you start a project, but you can make sure a team has broad enough competencies to notice when they need another expert. "*	**Proposition 2.3** linking active mediation and creation of common frames of reference to exploration and exploitation is likely to improve boundary spanning between knowledge domains Illustrative quote: *"002: Innovation Center is characterized by project work and cross organizational collaboration, which require knowledge sharing across all barriers to deliver fast enough results to keep up with competition."*	**Proposition 2.1** Exploitative process knowledge with close bonds to business units are central to continued high exploratory performance from the exploratory team**.** Illustrative quote: *"020: S&D starts an innovation unit, spawning the discussion: should innovation drive BM's or vice versa?***"** **Proposition 1** The mixed-mode innovation process has the following two characteristics: **1.1)** it follows a messy structure to the extent that process management tools that assume a linear flow will fail to provide team-level support, and **1.2)** it can be effectively supported by detaching the three primary support functions of knowledge, decision, and foresight from the innovation process management models. Illustrative quote: *"Much confusion as to where actual projects and innovation activities are placed in the process model exists. "*	**Proposition 2.4** New procedural knowledge is likely to be adopted faster if it is tied to technological innovation. Illustrative quote: *"001: "Power" dominates knowledge-production and sets KM agenda, because they have the technical assets."* **Proposition 2.5** The exploratory and exploitative phases in the ambidextrous organization are likely to be able to be synchronized via innovation portfolio management. Illustrative quote: *"The Energy flex-house could extract knowledge on how micro-production interacts in a system."* *"Merger between mobility and energy has created a demand in DE for integrating entirely new competencies."*

(Table continued on next page)

	Dynamic capabilities in a knowledge resource perspective: How may dynamic adaption of knowledge-resources and routines be supported			
Output type:	**Human Capital**	*Output type:*	**Human Capital**	*Output type:*
Decision • Routines	**Proposition 3.1** Decisions taken socially on the specialist level with an equal weight on deterministic systems analysis and methodical constructivist foresight are more likely to yield informed decisions for innovation than decisions at management level based on pure analytics. Illustrative quote: *"004: My decision process is based on "business as usual", even though I strongly believe that a crisis will occur.* *"MAS, which creates forecasts etc. announce that they are tired of university collaborations, because universities are behind with theory."*		**Proposition 3.2** The decisions in Proposition 3.1 are unlikely to occur without specific tool support. Illustrative quote: *"002: we need to institutionalise the story about the future energy system."* *"ELSIM should be developed to include exploration of scenarios for local solutions, such as micro wind (WAF)"*	
Foresight • Routines	**Proposition 4.3** Deliberate teaching of a foundation for understanding foresights correctly for the entire innovation team is likely to improve the speed and accuracy at which it adapts to new conditions. Illustrative quote: *"003: We develop for mega-trends, thus a central capability is holding on to projects for an extremely long time, up to 20 years. "* *"Dong Energy needs continues improvement of market simulation and technology simulation competencies (the art of the possible)"*		**Proposition 4.1** A clear picture where a project is, on the continuum between exploration and exploitation, combined with a clear role of foresight, is likely to improve the speed at which such project can be absorbed into a business unit for exploitation. Illustrative quote: *"Scenario models, once big in NESA, resurfaces in the Innovation Centre, but are largely left to MAS forecasting."* *"The "pictures of the future" (made in collaboration with Siemens) takes the shape of a commonly agreed future for energy technologies that DE was already exploring. "*	**Proposition 4.2** Methods for creating foresights and innovations for the mid-future are likely to help connecting innovations for the short and long term. Illustrative quote: *"Dong Energy needs that "the future system" exist to make decisions, which leads to establishing collaboration with J.Ø. from DTU, who's PowerLab can emulate any connected future. "* *"005: Strong scenario processes lead east DK to be ready for liberalization of the power market long before west DK"*

An explanation for understanding dynamic capabilities (outlined in Table 13), lies in the knowledge backgrounds from which the innovation projects were created, e.g. the electric car projects:

> BetterplaceDK builds on knowledge regarding grid integration and balancing services as well as the external partnership with Betterplace.

> Etrans builds on knowledge regarding demand-profile modelling and sales as well as an external consortium-collaboration with 14 other industrial actors.

For each of the six projects, it was observed that the company was entering new markets where they had a knowledge resource and/or capability that they believed would be more rare in the market they entered than in the market it was developed and thereby a source of competitive advantage.

> 012: We tried peak-shaping based on economic incentives, but consumers doesn't respond, that is why we need UDI (user driven innovation) and e-mobility

> 008: Transformation in product understanding: from heat/gas/power to 'Mobility costumers are also energy customers'

> 012: Knowledge on new technologies require special internal political processes, we learned this from the heatpumps.

After entry, the resources and capabilities were transformed according to the needs of the new market, supported by the dynamic capabilities, e.g. the move into the e-mobility market described above (BetterplaceDK and Etrans): The core-capability of creating complex multifactorial scenarios for socio-technical changes within the energy sector was introduced into the newly entered automotive market under influence of the dynamic capability of how to change these heavy computational scenarios to new contexts. This dynamic capability had been practiced earlier within the company through a series of mergers between companies from the oil sector and the utilities sector. Here, scenario techniques had been moved between these sectors. The success of these operations was observed to rely heavily on the company's ability to integrate knowledge from new innovation team members, coming from the target sector with the knowledge on foresight models and value creation in existing markets, residing within each their groups of people. Based on the experiences from earlier, the integration was facilitated by new concrete innovation projects, where the requirements for the new scenario-tool would become clear (see also propositions 4.1 – 4.3)

5.6 Initial validation

The explanatory model in Table 13 was presented to the head of the innovation center for confirmation. As a result, the company decided to introduce the model and test it for three different purposes. First, it was successfully used as a template for restructuring the communication of the value created by innovation center projects to top management. Second, it was used similarly for restructuring the communication of the value created by innovation center projects to the business units. Finally, it was used to compare the European Union's Horizon 2020 innovation projects with the seventh framework program in terms of intangible sunk costs. Through this initial validation process, we confirmed the accuracy of the constructs.

6   Conclusion

The aim of our study to undertake a real-time study of the mechanisms through which dynamic capabilities that support multi-mode innovation are developed and evolve on the level of the innovation team. We studied this process by using a coding scheme built primarily on intellectual capital theory, innovation process theory, and knowledge management. Existing theory does not explain how the specific capabilities for balancing exploration and exploitation are created. Therefore, our study contributes to theory on dynamic capabilities with a set of specific propositions and a framework for understanding the team level of capability creation. We consider our case to be informative as we were able to observe the innovation in the making, which is a rare opportunity when studying any kind of innovation; this situation enabled us to study directly how the company responded to the change by changing operational capabilities. Evidence from our study suggests that an incumbent organization can adapt to a disrupted environment by carefully supporting knowledge, decision and foresight through the deliberate creation of dynamic capabilities along the four intellectual capital dimensions. However, our study also shows that

solving the issue of adaptation through the mechanistic redesign of processes is, at best, challenging. Thus, the study advocates high involvement at all levels of the organization as operational capabilities are developed by the innovators while they are creating the innovations.

Our study contributes to the theories intellectual capital and dynamic capabilities on a team level. Prior theory suggests that exploration and exploitation can be balanced via either punctuated equilibrium or organizational ambidexterity and that dynamic capabilities are created at the management level. However, there are few empirical studies of the creation of dynamic capabilities and transformation of operational capabilities necessary for innovation at the team and individual levels. In this study, we address this gap (see Table 14).

Table 14: Summary of theoretical contributions

Proposition	Contribution to theory
Proposition 1 Innovation process support	• Confirmation of the messy process view • Identification of knowledge, decision and foresight as generic innovation support functions
Proposition 2 Support of knowledge-related activities	• Ambidextrous organizations will, over time, be forced to transfer innovations between exploratory and exploitative departments, which make synchronization a key challenge for performance. • Exploratory innovators works in a cycle of knowledge creation that moves between integration and experimentation
Proposition 3 Support of decision-related activities	• In situations of radical uncertainty, a balance needs to be struck between social sense making and historical data analysis in order for decisions to be informed and persuasive, but current tools doesn't support this.
Proposition 4 Support of foresight-related activities	• Foundation for foresight-interpretation will improve the speed and accuracy of the innovations teams' adaptation to new contexts. • Creation of mid-term innovation, based on mid-term foresights, will support slow disruption, but requires new tools
Framework for analysis	• Extension of intellectual capital theory with the artifactual capital proposition • A framework for studying the creation of disruptive innovation capabilities on the level of innovation teams

One significant limitation of this study is that it employs a single embedded case study design. Therefore, the findings cannot, in a statistical sense, be generalized, and the validity of these constructs in other contexts must be established. However, we expect our results to be valid in similar industry cases in which exploration is actively pursued through an ambidextrous and/or punctuated equilibrium approach. Correspondingly, it would be fruitful for further research to

perform comparative studies of these findings in other large companies whose products have differing levels of complexity or whose ownership structures are different. Such research would make it possible to identify under what conditions the theory is valid. In addition, a natural next step would be the creation of support tools for innovation teams based on the mechanisms that we have identified. These tools would be beneficial for research because they would further validate these findings and, through the validation process, lead to new insights into the practices of innovation teams. Furthermore, they would assist managers and innovation teams in practice. In the case of energy technology and, more importantly, transitioning to a sustainable energy system, this study has shown that incumbent companies have great opportunities to drive the change towards a sustainable future but also that the management of such a change will benefit from the assistance of the management research community.

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Appendix A – Definitions of codes

Complete coding scheme for decision

Categorized Codes	Definition
Practices	
External authority	Decision is driven by advice from an external authority such as Gartner or Bain
Persuade network to support	Key stakeholders are mobilized to drive decisions through political processes
Core capability utilization	Decision is based upon the best utilization of the firms core capabilities
Business model Alignment	Alignment with the business model(s) are used decisive factor
Fit requirements	The decision is taken based on fit with a specific set of limiting requirements
Fit foresight	The decision is taken based on fit with one or more future expectations
Best requirements fit	Decision based on which alternative is the best fit to a set of requirements
Best foresight fit	Decision based on which alternative is the best fit with future expectations
Decision-maker behavior	
Explicit Personal	Deliberately taken by an aware individual
Explicit Social	Deliberately taken by an aware group of individuals
Implicit Personal	Taken by a person without him being readily aware of making a decision
Implicit Social	Taken by a group of individuals, without these being readily aware of it
Centralization	
Centralized	Decision making is sought done centrally by e.g. a decision board or the CEO
Intermediate	Decisions are done centrally, but with high direct involvement of the team
De-centralized	Decision making is sought done locally in organizational units by e.g. teams
Object behavior	
Rational	Decision pertaining to a rational defined future e.g. upgrades in the grid
Hybrid	Decisions pertaining to a hybrid between rational and irrational future
Irrational	Decisions Pertaining to an irrationally defined future e.g. user behavior

Complete coding scheme for knowledge

Categorized Codes	Definition
Innovation Phase	
Front end	Covers the early part of the NBD process, in which goals are not yet defined
Transition	Transition of results from the front end to product development
Product development	Goal-directed phase in which a goal and the means to reach it have been defined
All Phases	All of the above phases
Exploitation of Knowledge	
Concentration	Activity concentrating knowledge in a super-node, e.g., a domain specialist
Dissemination	Distribute and share knowledge either in codified or personal form
Externalizing	Activity making people's personal knowledge explicit, e.g., writing words down
Collecting	Adding and combining knowledge in, e.g., a database for later retrieval
Codified dissemination	Transfer of explicit knowledge directly, e.g., by writing an article
Personal dissemination	Transfer of knowledge without explicating it first, e.g., through apprenticeship
Exploration of Knowledge	
Reflection	Processing of new knowledge at the individual or social level to create clarification
Monitoring	Surveillance of knowledge fields and new ideas internally and externally
Experimenting	Creation of new knowledge and ideas through experimentation in a wide sense
Integrating	Combining knowledge with the aim of creating new ideas and concepts
Barriers for Knowledge Transfer	
Preconception of knowledge quality	The recipient's perception of the source as an authority within its domain
Ease of access	How easy the process of establishing a link to a source or recipient is
Deliberate restricted access	Barrier created to protect IPR, strategies and other sensitive information
Mediation	Absence of mediating device, e.g., drawings, or a facilitator that conveys knowledge
Cause for interaction	Lack of reason to interact with potentially interesting knowledge sources
Common frame of understanding	Absence of social frames of understanding, e.g., shared business model/vision
Accessibility of source	How able the seeker is to locate and utilize a needed knowledge source
Knowledge level distance	Relative distance in knowledge level between the source and recipient
Interpretation difference	Barrier created by significant differences in cognitive frames of the people interacting
Novelty of Knowledge	
New to world	Knowledge completely new to everyone in the world
New to firm	Knowledge that is completely new to the firm but not necessarily to others
New to organizational unit	Completely new knowledge to, e.g., the team but not necessarily to others
Partly known/adapted	Partly known knowledge but adapted to a new specific context of use
Existing	Knowledge already known widely in the firm, unit and world in general
Knowledge Domain	
Business model and processes	How to develop the idea or technology into an appropriate business concept
Development funding	Knowledge on how to fund a project to develop the ideas or technologies at hand
Internal alliance creation	The political process by which internal support for ideas is generated
External alliance creation	Knowledge about how support, e.g., visions through alliances with universities
Regulatory environment	Process knowledge on how regulatory frame affects ideas/can be affected
Insights into user's world	Knowledge about the behavior of users and the reciprocal effects on innovations
Dynamics of the market	Macro-scale market insights about market forces, entry barriers, and fluidity
Technical characteristics	Micro-level knowledge about the characteristics of the specific technology at hand
Synergies with energy system	Macro-level energy system: Interactions between elements in the power grid
Energy resource reliance	Insights into a strategic energy resource future, e.g., biomass sourcing or wind
All domains	How to develop the idea or technology into an appropriate business concept
Knowledge Retention Strategy	
Spread and keep	Obtain knowledge from internal source, thereby spreading and securing it
Create internally, keep	Create the knowledge internally and evolve competencies at the same time
Obtain externally, keep	Consult external sources but learn and develop new internal competencies
Consult external source	No retention – External sources are used to provide specific answers

Complete coding scheme for foresight

Categorized Codes	Definition
Source temporality	
Past experience	Experiential knowledge is sought out e.g. historical data or solutions
Current context	Contextual knowledge is sought out for description of the current world
Future contexts	Knowledge about the future is sought out, describing opportunities, goals etc.
Source type	
Internal political	Source of knowledge inducing expectation is internally political e.g. manager
Internal specialist	Source of knowledge inducing expectation is internally specialist e.g. R&D Pro.
External political	Source of knowledge inducing expectation is externally political e.g. politician
External specialist	Source of knowledge inducing expectation is externally specialist e.g. consultant
Model paradigm	
Determinist	Principal actor's view is that there is one definable future
Constructivist	Principal actor's view is that there are multiple equally plausible futures
Future temporality	
Near future	The expectation tries to assess the near future (Tactic)
Mid future	The expectation tries to assess the medium term future (Strategic)
Far future	The expectation tries to assess the far future (Visionary)
Formal acceptance	
Personal	Expectation is held as a personal belief, shared by no or few others
Social	Expectation is socially negotiated and commonly accepted in the team
Codified	Expectation is written down and represents the company's official expectation
Relationship	
Normative	Desired future that actors or groups will actively work towards realizing
Desired	A future that is desired by the actors or groups but not actively pursued
Indifferent	Expected evolution of the future, however no actors are emotionally attached
Feared	An expected future that the principal actor fears, but doesn't act to avoid
Threatened	The principal actor considers future threatening and actively counteracts it
Methodology	
Method	Expectation created through use of a formal method e.g. scenario or roadmap
No Method	Expectation created with no use of formal methods – e.g. personal beliefs
Role	
Strategist	Used for exploring new business fields, generate visions and gain consensus
Initiator	Works as an initiator of projects and activities e.g. by identifying needs & techs
Opponent	Expectation is used to perform "sanity checks" of concepts to increase quality

Appendix A1 – Examples of coded segments from observations, interviews, and workshops

Data and metadata			Structural Codes			Codes Across Groups			Knowledge					
Data Point	Quarter	Data	Data Type	Multiplier	Intellectual Capital	NBD Phase	Innovation Purpose	Knowledge type	Exploitation	Exploration	Barriers for knowledge Transfer	Novelty of Knowledge	Knowledge Domain	Knowledge retainment strategy
Innovation Center	Q2	007: IC is a huge head with a very small body: much competence, but we need to mobilize int. +external muscle	Field Notes	6	Human Capital	Transition (Pre to Pro)	Strategic positioning	0		Integrating	Lack of common frame of understanding	New to Firm	External Alliance Creation	Get externally, keep
Innovation Center	Q10	003: We sold our assets in Norwegian hydro because IC failed to communicate to the deciders what would be important in the future	Field Notes	1	Structural Capital	Project (Open ended)	Strategic positioning	Temporary Static	Dissemination	Integrating	Lack of common frame of understanding	New to Org. Unit	Technical Characteristics	Spread and Keep
Innovation Center	Q4	002: IC is characterized by project work and cross organizational collaboration, which require knowledge sharing across all barriers to deliver fast enough results to keep up with competition.	Field Notes	7	Relational Capital	All phases	Knowledge Building	Temporary Static	Dissemination	Integrating	Lack of common frame of understanding	New to Firm	All	Spread and Keep
Innovation Center	Q3	002: It is essential for idea management that new ideas are brought in via (new) products and services	Field Notes	6	Artefactual Capital	0	Knowledge Building	Temporary Static	Externalising	Integrating	Lack of mediation	New to Firm	All	Create internally
e-Trans	Q4	001: We need less joint learning and more meritocracy, with KDS taking knowledge-merited leadership	Field Notes	6	Human Capital	Project (Open ended)	Knowledge Building	Temporary Static	Collecting	Integrating	Lack of mediation	New to Firm	Insights into user's world	Get externally, keep
e-Trans	Q6	It is seen as a challenge that flexibility concepts in general are placed right between the S and the D, where a Chinese wall is legally required	Field Notes	4	Structural Capital	Project (Open ended)	Knowledge Building	Temporary Static	Dissemination	Experimenting	Lack of common frame of understanding	New to Firm	Dynamics of the market	Get externally, keep
e-Trans	Q4	During both KDS and Andy WS a large effort is put into getting the Business Units (Sales & Distribution + Power) to participate	Field Notes	6	Relational Capital	Project (Open ended)	Knowledge Building	Dynamic (permanently)	Collecting	Integrating	Pre-conception of knowledge Quality	New to Firm	Internal Alliance creation	Consult external source
e-Trans	Q2	008: "teknik" becomes technology when "logos" is added through human interaction (activated "teknik")	Field Notes	2	Artefactual Capital	Project (Open ended)	Knowledge Building	0	0	0	0	0	0	Q2
Workshop 1	-	A Good phonebook on the VITAL	Transcript	-	-	All phases	-	-	Per. Dissemination	Monitoring	Accesibility of source	Partly Known / Adapted	All	Spread and Keep
Workshop 1	-	Technical Career Path	Transcript	-	-	All phases	-	-	Concentration	Experimenting	Lack of mediation	New to Firm	Technical Characteristics	Create internally
Workshop 1	-	Rotation of employees between projects	Transcript	-	-	Project (Open ended)	-	-	Per. Dissemination	Integrating	Lack of common frame of understanding	New to Org. Unit	All	Spread and Keep
Workshop 1	-	Minimal use of resources during implementation	Transcript	-	-	All phases	-	-	0	0	0	0	0	0
Workshop 2	-	Anchoring of "freedom" in management / Processes	Transcript	-	-	Project (G - Directed)	-	-	0	0	0	New to Org. Unit	Business model and processes	Create internally
Workshop 2	-	Get concrete activities and budget for working consciously with governance structures	Transcript	-	-	All phases	-	-	0	0	Accesibility of source	New to World	Development funding	Create internally
Workshop 2	-	Differentiate between project and project: We need open relationships in the project and closed relationships in the project	Transcript	-	-	Transition (Pre to Pro)	-	-	Cod. Dissemination	Integrating	Lack of common frame of understanding	New to Org. Unit	Business model and processes	Spread and Keep
Workshop 2	-	Diversity creates more innovation but requires openness - learn to listen in this situation	Transcript	-	-	Project (Open ended)	-	-	Collecting	Integrating	Lack of mediation	New to Org. Unit	All	Create internally
Interviews	-	So, it is more like they feel like they (the business units) are doing us a kind of favor by participating with their knowledge, and **I** would like it to be pull from them.	Transcript	-	-	All phases	-	-	Collecting	Integrating	Lack of common frame of understanding	Partly Known / Adapted	0	0
Interviews	-	First of all we have SCANNED the market, we have taken different segments: farmers, pig farmers and cow farmers and large hotels and school and public administration. A LOT of, what kind of energy they are using, district heating, electricity, oil, gas and () Did they pay all the taxes on energy and + if they didn't than we could pick up out the markets which are interested. Mainly the consumer who pay high + energy price.	Transcript	-	-	Preject (Open ended)	-	-	Collecting	Integrating	Lack of common frame of understanding	Partly Known / Adapted	0	0
Interviews	-	Yeah. ++There has been a LOT of PEOPLE COMING IN AND COMING OUT for the up-start meeting.	Transcript	-	-	Preject (Open ended)	-	-	Collecting	Integrating	0	New to Org. Unit	Internal Alliance creation	Spread and Keep
Interviews	-	And I have been talking about these routine meetings with POWER and PARTNERSHIP management which is very important part of knowledge management, I would say because we have to know what's going on, what's coming and what's going to be installed in the production units for green electricity and things like that.	Transcript	-	-	**0**	-	-	Collecting	Integrating	Accesibility of source	New to Org. Unit	Business model and processes	Spread and Keep

Data and metadata			Structural Codes			Decision				Foresight							
Data Point	Quarter	Data	Data Type	Multiplier	Intellectual Capital	Decision Practices	Characteristics of DM Behaviour in NBD	Centralised / Distributed decisions	Behaviour of Decision Object	Temporal mode of knowledge	Knowledge Source	Model of the future	Temporal mode of expectation	Acceptance degree	Relationship to expectation	Creation of expectation	Role of expectation
Innovation Center	Q2	007: IC is a huge head with a very small body: much competence, but we need to mobilize int. +external muscle	Field Notes	6	Human Capital	Business model Alignment	Explicit Personal	0	0	Current / Context	Internal Specialist	0	Near Future	Social	Threatening	No Method	Opponent
Innovation Center	Q10	003: We sold our assets in Norwegian hydro because IC failed to communicate to the deciders what would be important in the future	Field Notes	1	Structural Capital	Fit expectations	Explicit Social	Centralised	Rational	Future / Goals	Internal Specialist	Determinist	Far Future	Codified	Indifferent	No Method	Opponent
Innovation Center	Q4	002: IC is characterized by project work and cross organizational collaboration, which require knowledge sharing across all barriers to deliver fast enough results to keep up with competition.	Field Notes	7	Relational Capital	Business model Alignment	Explicit Social	Centralised	Hybrid	0	0	0	0	0	0	0	Opponent
Innovation Center	Q3	002: It is essential for idea management that new ideas are brought in via (new) products and services	Field Notes	6	Artefactual Capital	Fit requirements	Explicit Social	Centralised	Hybrid	Current / Context	Internal Political	0	Near Future	Codified	Normative	Method	Initiator
e-Trans	Q4	001: We need less joint learning and more meritocracy, with KDS taking knowledge-merited leadership	Field Notes	6	Human Capital	Core capability utilisation	Explicit Social	Intermediate	Irrational	Future / Goals	External Specialist	Constructivist	Far Future	Social	Normative	Method	Initiator
e-Trans	Q6	It is seen as a challenge that flexibility concepts in general are placed right between the S and the D, where a Chinese wall is legally required	Field Notes	4	Structural Capital	Business model Alignment	Explicit Social	Intermediate	Hybrid	Future / Goals	External Specialist	0	Mid Future	Social	Normative	No Method	Initiator
e-Trans	Q4	During both KDS and Andy WS a large effort is put into getting the Business Units (Sales & Distribution + Power) to participate	Field Notes	6	Relational Capital	0	0	0	0	Future / Goals	External Specialist	0	Far Future	Social	Normative	Method	Initiator
e-Trans	Q2	008: "teknik" becomes technology when logos is added through human interaction (activated "teknik")	Field Notes	2	Artefactual Capital	0	0	0	0	0	0	0	0	0	0	0	Initiator
Workshop 1	-	A Good phonebook on the VITAL	Transcript	-	-	0	0	0	Rational	Current / Context	Internal Specialist	0	Near Future	Personal	Desired	0	Initiator
Workshop 1	-	Technical Career Path	Transcript	-	-	Core capability utilisation	0	0	Irrational	Future / Goals	Internal Specialist	0	Near Future	Personal	Desired	0	Initiator
Workshop 1	-	Rotation of employees between projects	Transcript	-	-	Core capability utilisation	Explicit Personal	Centralised	Irrational	Current / Context	Internal Political	0	Near Future	Personal	Desired	0	Strategist
Workshop 1	-	Minimal use of resources during implementation	Transcript	-	-	0	0	Centralised	Rational	0	0	0	Near Future	Personal	Desired	0	0
Workshop 2	-	Anchoring of "freedom" in management / Processes	Transcript	-	-	Business model Alignment	Implicit Personal	Intermediate	Irrational	Current / Context	Internal Specialist	0	Near Future	Personal	Desired	0	Initiator
Workshop 2	-	Get concrete activities and budget for working consciously with governance structures	Transcript	-	-	0	0	Centralised	Rational	Current / Context	Internal Political	0	Near Future	Personal	Desired	0	Initiator
Workshop 2	-	Differentiate between project and project: We need open relationships in the preject and closed relationships in the project	Transcript	-	-	0	Explicit Social	Intermediate	Rational	Current / Context	Internal Political	0	Near Future	Personal	Desired	0	Strategist
Workshop 2	-	Diversity creates more innovation but requires openness - learn to listen in this situation	Transcript	-	-	Fit expectations	0	De-centralised	Irrational	Future / Goals	External Specialist	Constructivist	Near Future	Personal	Desired	0	Opponent
Interviews	-	So, it is more like they feel like they (the business units) are doing us a kind of favor by participating with their knowledge, and I would like it to be pull from them.	Transcript	-	-	0	Implicit Social	De-centralised	0	0	Internal Political	0	0	0	0	0	Opponent
Interviews	-	First of all we have SCANNED the market, we have taken different segments: farmers, pig farmers and cow farmers and large hotels and school and public administration. A LOT of, what kind of energy they are using, district heating, electricity, oil, gas and () Did they pay all the taxes on energy and + if they didn't than we could pick up out the markets which are interested. Mainly the consumer who pay high + energy price.	Transcript	-	-	Fit requirements	0	0	Rational	Current / Context	External Specialist	Determinist	Near Future	Codified	0	Method	Strategist
Interviews	-	Yeah. ++There has been a LOT of PEOPLE COMING IN AND COMING OUT for the up-start meeting.	Transcript	-	-	0	Implicit Social	0	0	0	0	0	0	0	0	0	0
Interviews	-	And I have been talking about these routine meetings with POWER and PARTNERSHIP management which is very important part of knowledge management, I would say because we have to know what's going on, what's coming and what's going to be installed in the production units for green electricity and things like that.	Transcript	-	-	Core capability utilisation	Implicit Social	De-centralised	0	Future / Goals	Internal Specialist	0	Near Future	0	Normative	Method	Initiator

1 Knowledge

1.1.1 Knowledge Stability
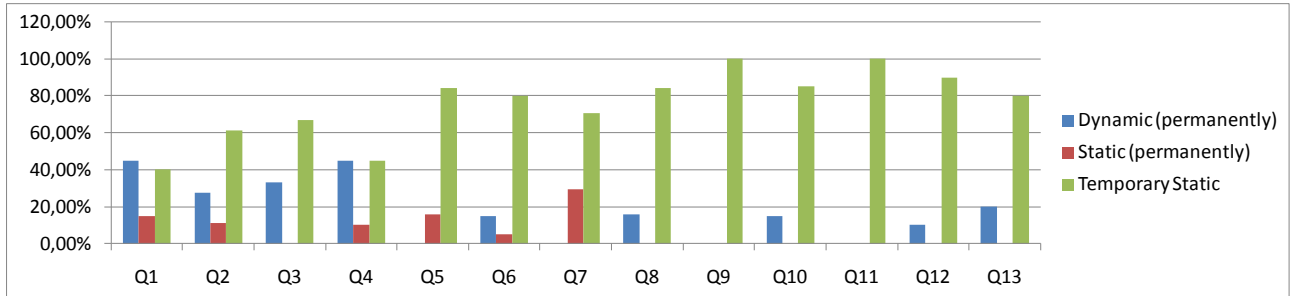
1.1.2 Exploitation of knowledge
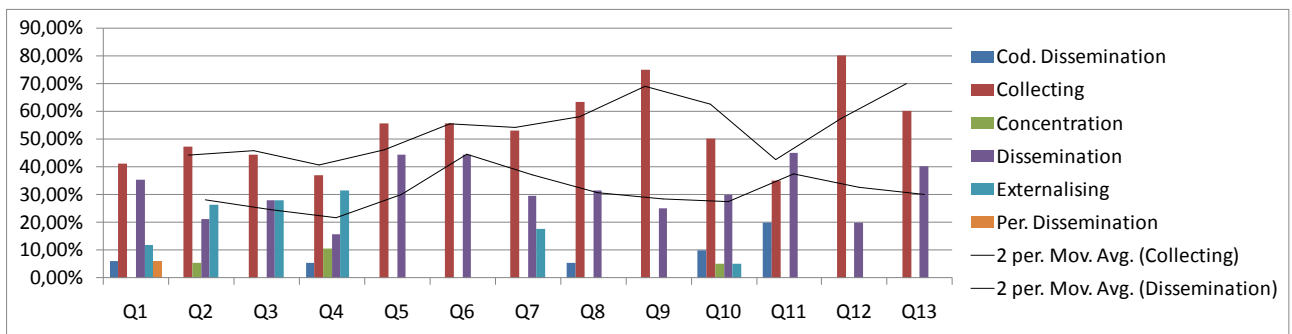
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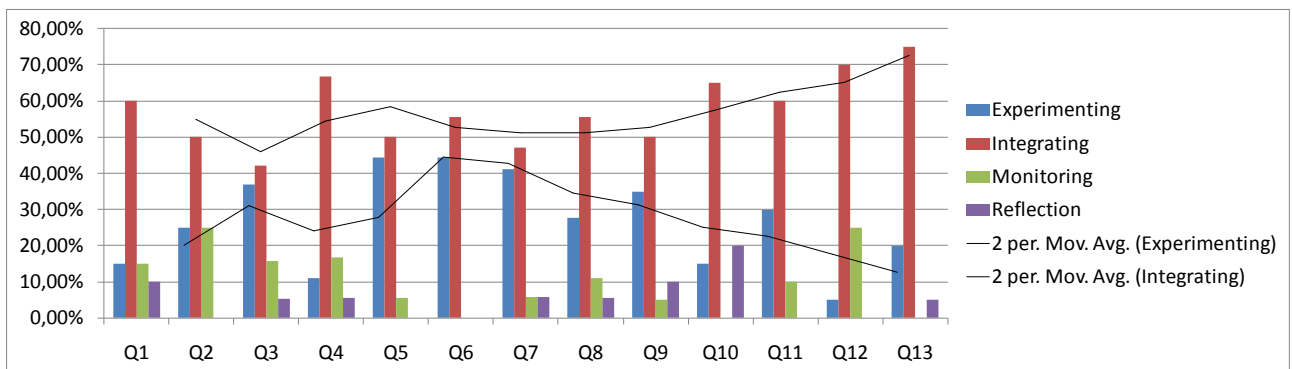
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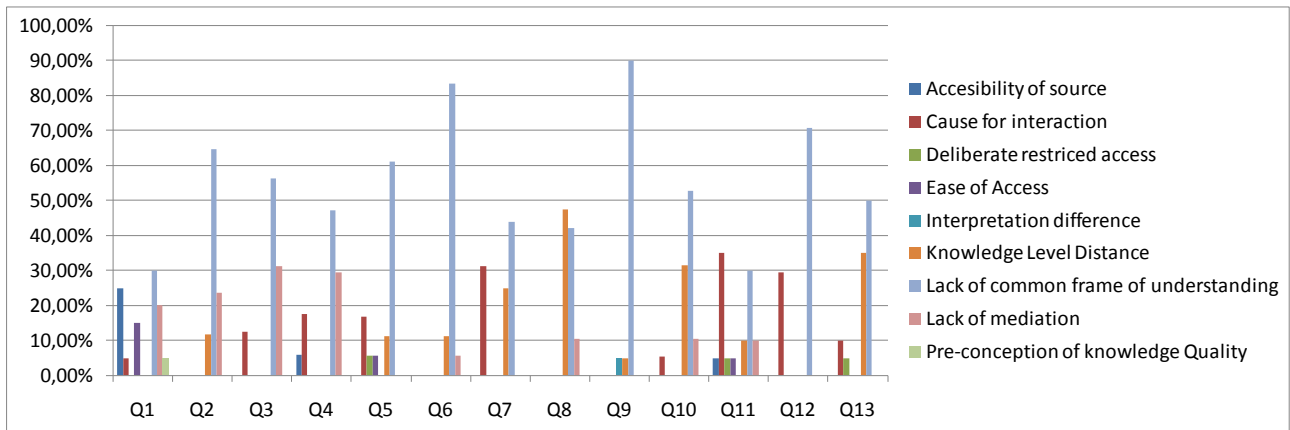
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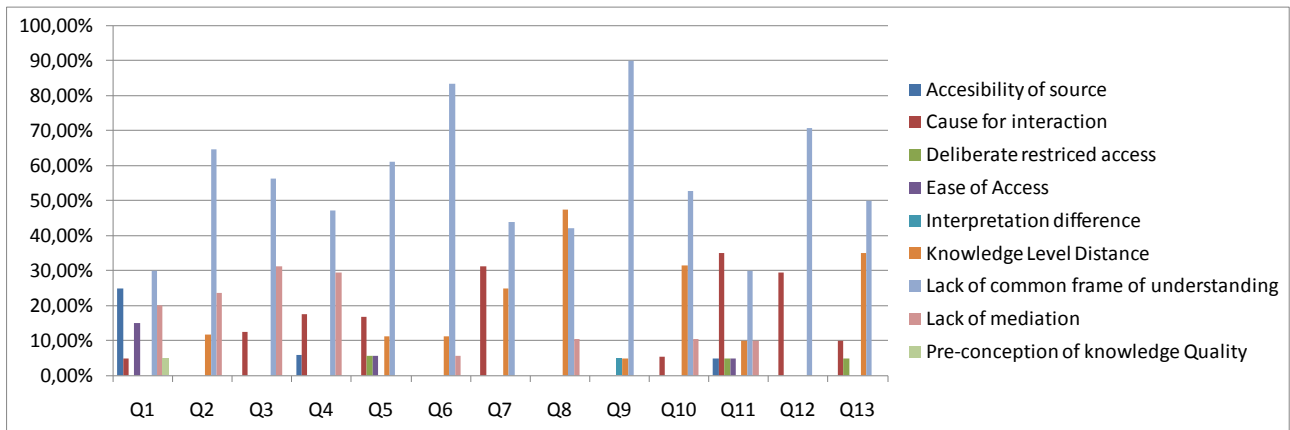
1.1.6 Knowledge domain
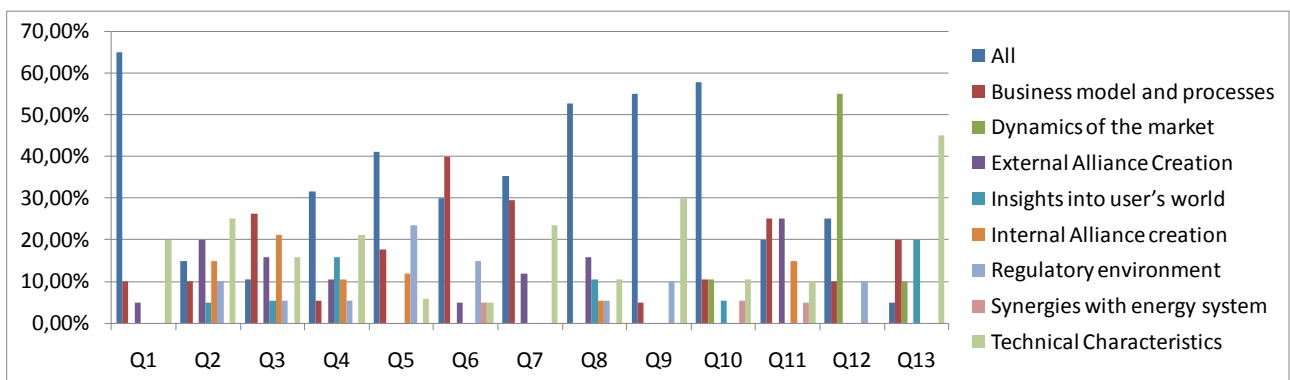
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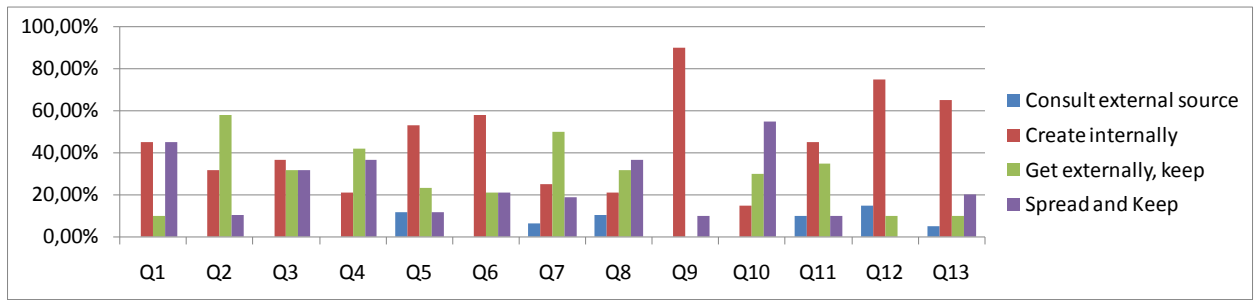
2 Decision

2.1.1 Practices
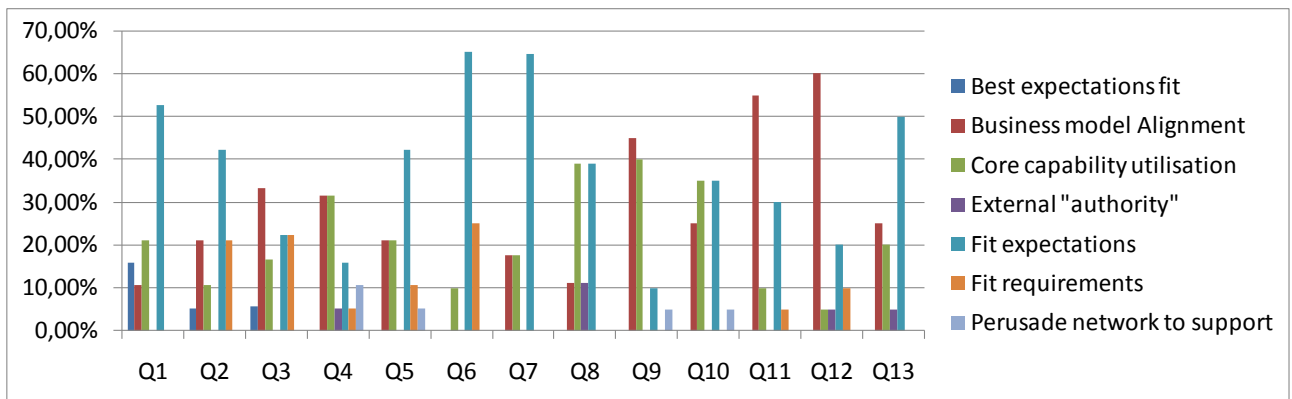
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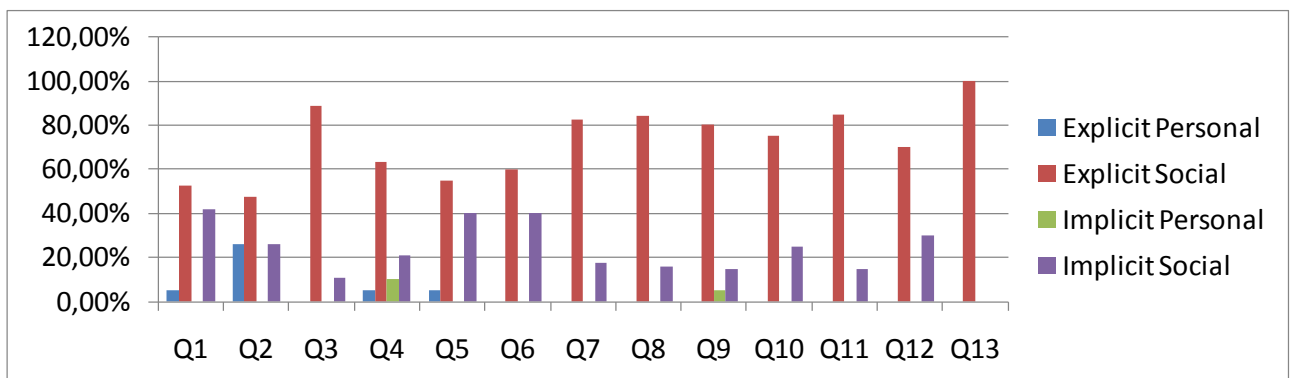
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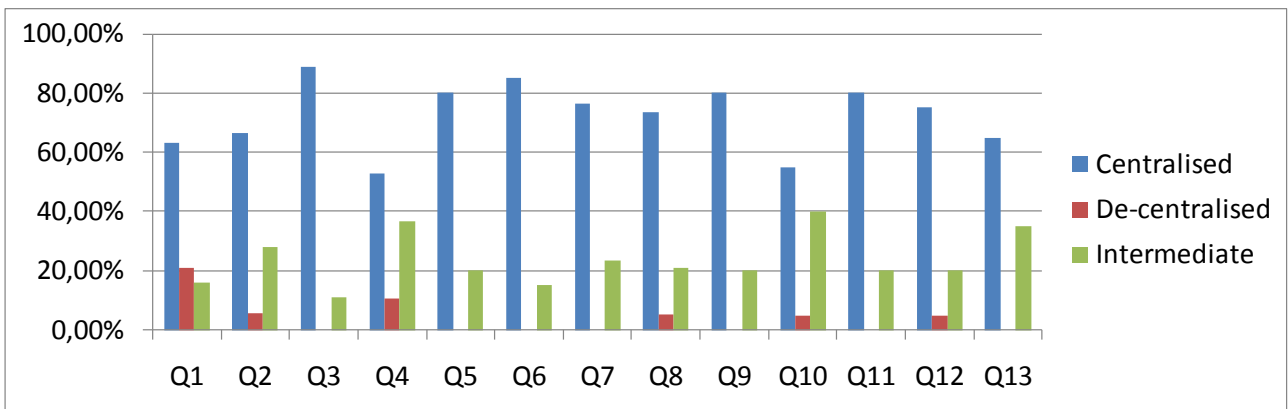
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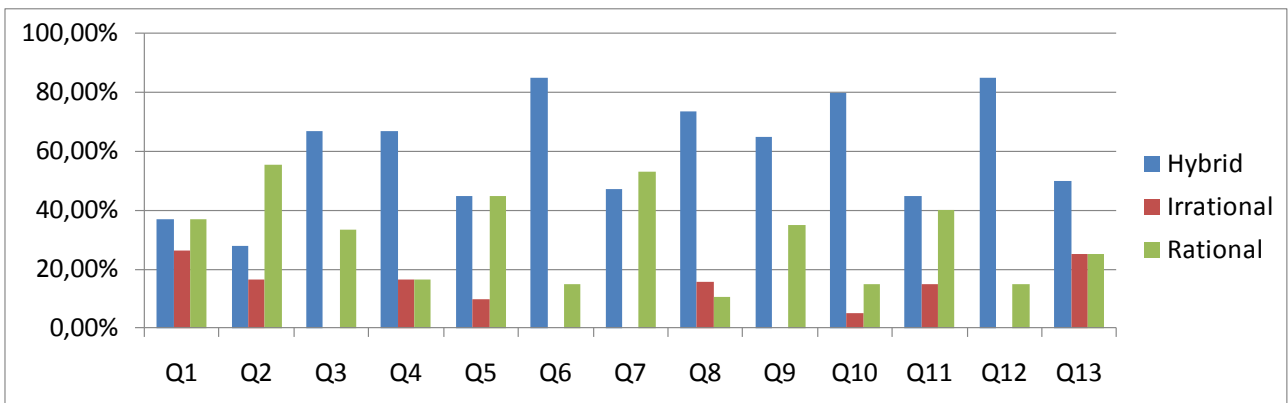
3 Picture of the future

3.1.1 Source temporality
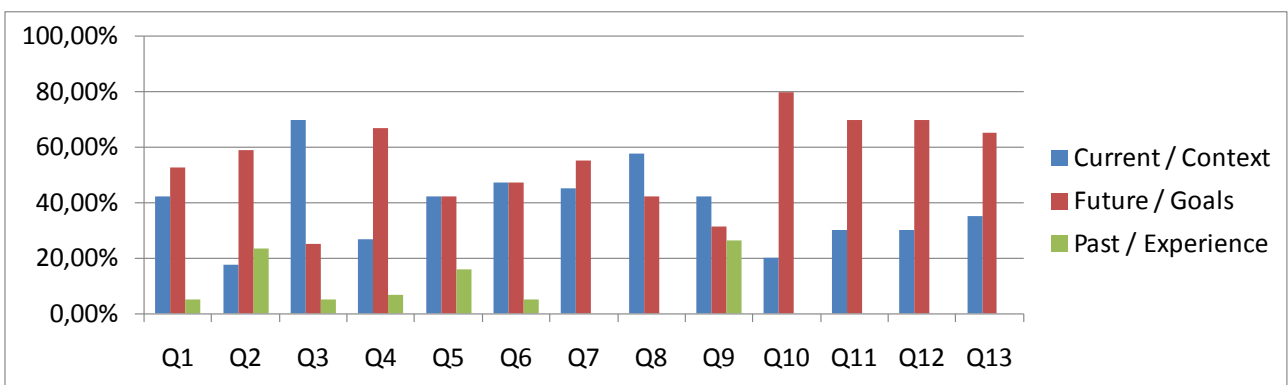
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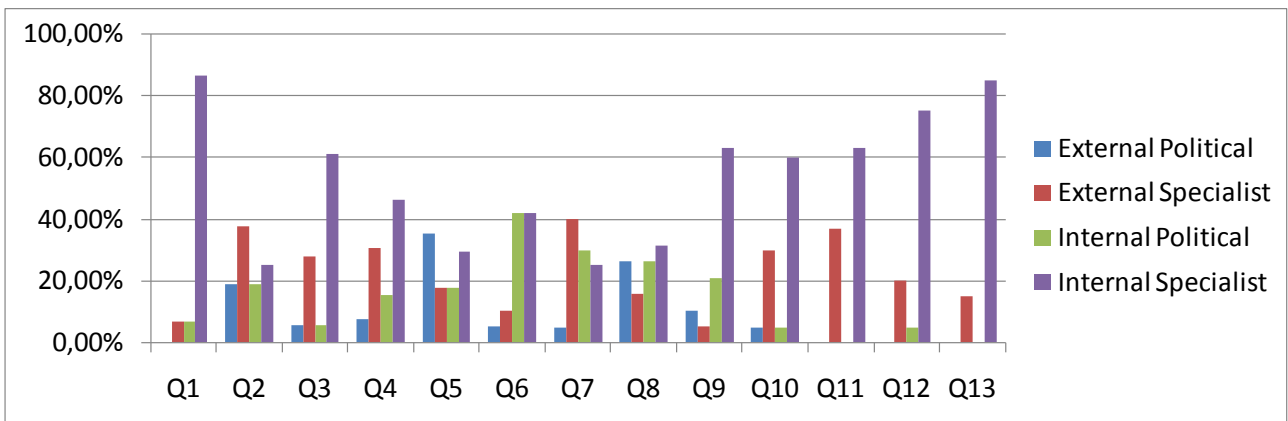
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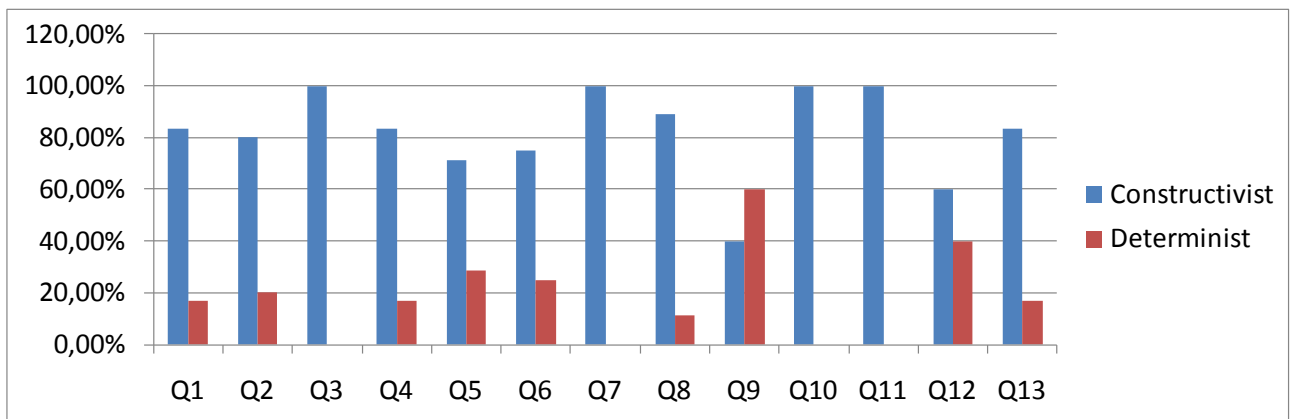
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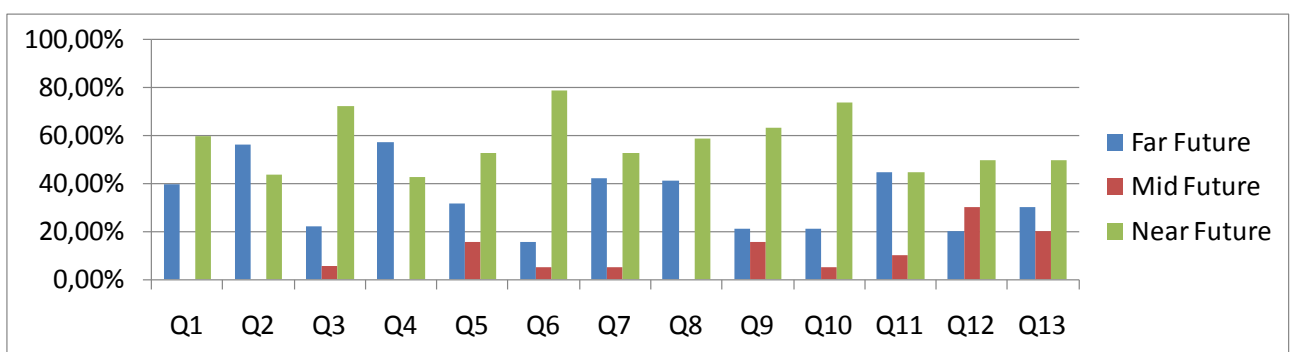
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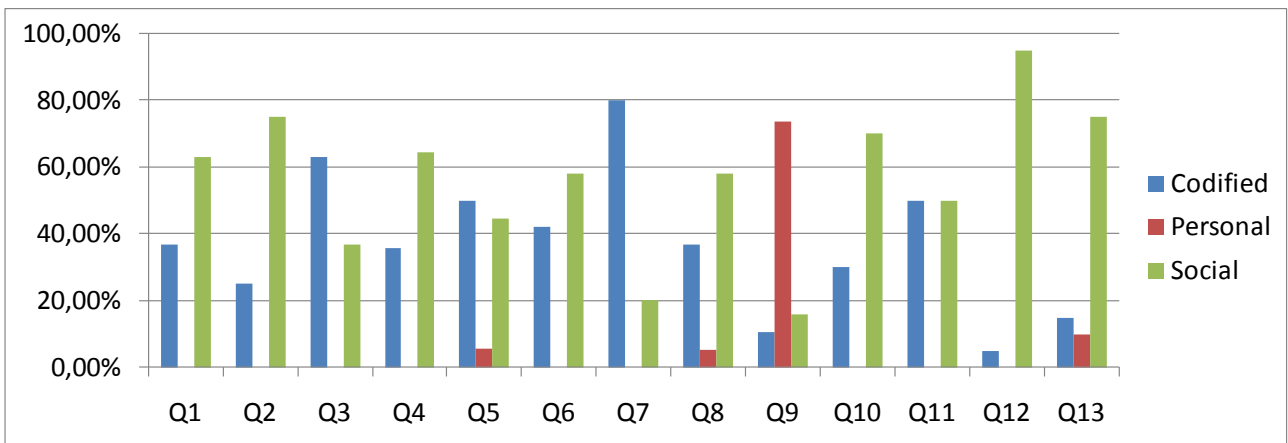
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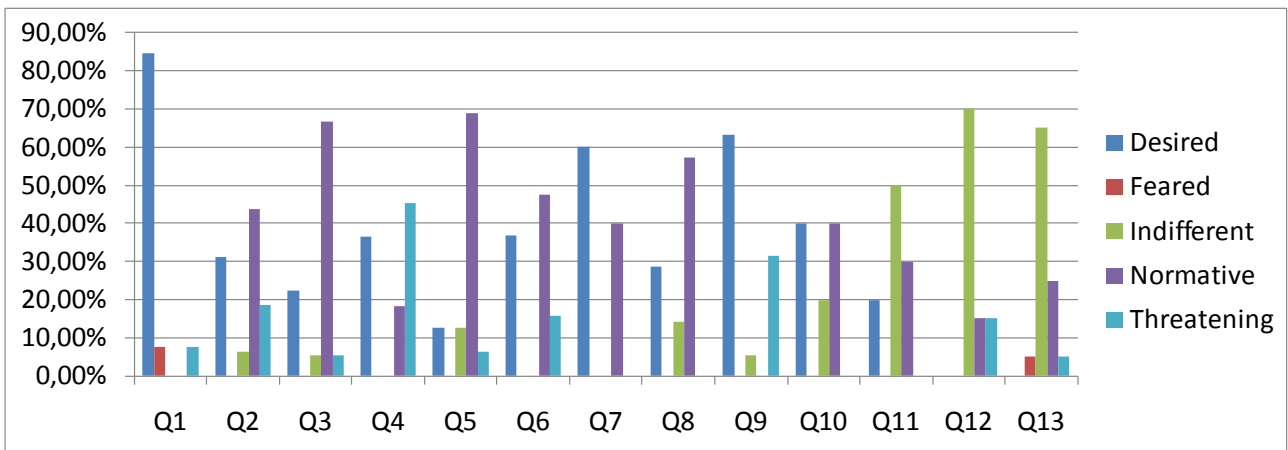
3.1.7   Methodology
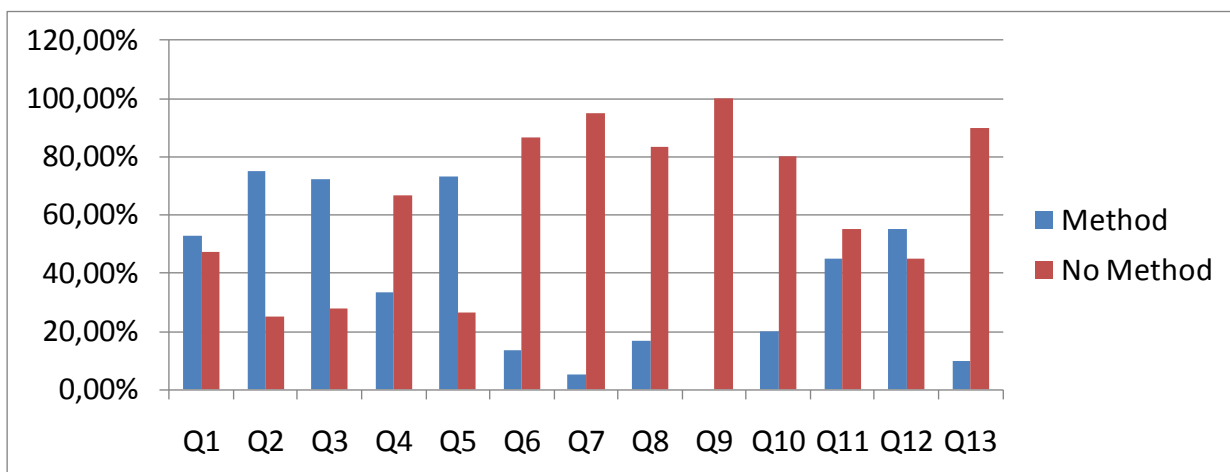
3.1.8 Role
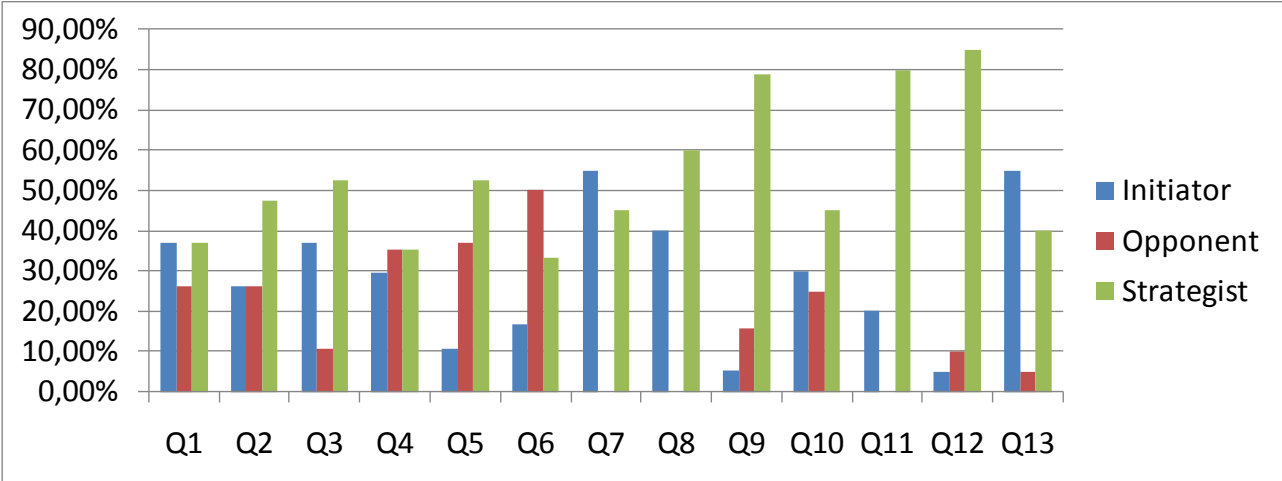
Boundary spanning in multidisciplinary design teams

Multidisciplinary design teams lack a common understanding of each other's knowledge domains, and during highly radical innovation, this challenge increases due to increased knowledge diversity. The effects of a boundary object on these types of design teams in the energy sector was studied with the aim of investigating whether a boundary object in the form of a simulation game could improve their performance. The research is conducted by testing the game through implementation in a company and through a controlled experiment. The outcome indicates that the designers reacted positively, learned key concepts from other domains, changed their behaviour and produced better results as a result of the simulation game's ability to address semantic, syntactic and pragmatic barriers between knowledge domains.

Empirical studies have indicated that multidisciplinary design teams perform better than mono-disciplinary teams in several ways, e.g., innovation height and lead time (Taylor & Greve, 2006). The use of multidisciplinary design teams is increasingly becoming the preferred approach in product development in companies as their products encompass an increasing variety of technologies (Hoegl et al., 2004); (Granstrand & Sjölander, 1990). In addition, the concept of integrated product development, adopted in some form by many companies, adds to the variety of disciplines present on teams because product development, marketing and production are all involved in the design team (Andreasen & Hein, 1987). Since the beginning of the deliberate design of engineering approaches in industry during the post-Second World War era, integration of knowledge across disciplinary domains has been a central issue. The challenge has been in integrating science with engineering to collaborate on complex tasks such as constructing nuclear power facilities (Beckman & Barry, 2007; Cross, 2007). This integration was facilitated by formalising the engineering design methodology to create a common language across domains (Simon, 1988) and inspired the start of design re-

search in the 1960s (Cross, 2007). In contemporary design research, communication and teamwork, i.e., across domain boundaries, is still receiving significant attention. For example, Kleinsmann *et al.* (2010) describe the complex picture of knowledge integration in new product development teams, and Carlile (2004) proposes a framework for managing knowledge across boundaries, focusing especially upon innovation. The attention to knowledge domains is warranted, as successful integration across knowledge domains is one of the central keys to unlocking the innovative potential of design teams in industry. This idea is underlined by Leonard-Barton (1995)'s statement that most innovation occurs at the boundaries between disciplines or specialisations and also underscores why it is so difficult to create and maintain innovation (Carlile, 2004).

Table 1: Hierarchy of technological innovation types

First level	Second level	Definition
Disruptive innovation		Innovation based on technologies that bring a very different value proposition to market. These typically start with performing worse than mainstream innovations and addressing fringe customers, but end out completely changing the rules of the game.
Sustaining innovation	Radical innovation	Innovation leading to great improvements in the performance of a product, in the eyes of the users.
	Incremental innovation	Innovation leading to minor improvements in the product, in the eyes of the users.

Many types of innovations exist and these can be classified according to the outcome i.e. technologies, products, processes, business models, or a combination of these. Innovation can also be classified to the extent to which it departs from the paths of earlier innovations (See Table 1). Sustaining innovation aims performance improvements along the lines of what customers value. These innovations can be from radical to incremental in nature. Disruptive innovation brings a completely new value proposition to the market, which disrupt existing structures and companies (Berends et al., 2007; Dodgson et al., 2008; Markides, 2005). An example of a disruptive innovation is the transistors that were disruptive relative to vacuum tubes. The notion that most innovation occurs in the boundaries between knowledge domains

is valid at all levels, with the main difference being that the distance between domains tends increase with innovation height. Therefore, support for crossing knowledge boundaries are expected to improve innovation at all levels, which is essential in a company where design teams over time are involved in projects aiming at creating innovation on several levels on this continuum of innovation height.

Knowledge domains are simultaneously drivers of and barriers to innovation (Carlile, 2002), and the same phenomenon is observed within collaborative design projects (Kleinsmann & Valkenburg, 2008). Thus, the successful integration of domains is far from a trivial task and requires carefully crafted support methods and boundary spanning approaches. The role of boundary spanners was described by Adams (1976) as being among the most demanding tasks for project managers, causing various negative issues, such as role stress, role conflict and role ambiguity, if not supported properly. This finding is further supported by Ancona & Caldwell (1992), who observed that the quality of boundary spanning affects a team's performance in terms of efficiency, quality, technical innovation, adherence to schedule and budget, and work excellence. Ancona & Caldwell (1990) concluded that the cognitive models and skills of a group's leader, in the role of a boundary spanner, influence the group's external strategies, which in turn influence how group members perceive and approach their environment. These perceptions and approaches have further significant effects on a group's capacity for absorbing knowledge from the external environment (Cohen & Levinthal, 1990). Knowledge asymmetries between groups and individuals from different domains are simultaneously barriers to and drivers of effective innovation performance in a team because of the deep knowledge generated within a domain together with the asymmetric interactions between domains (Carlile, 2002; Leonard-Barton & Leonard, 1998). Knowledge asymmetries prevent the innovation function in a company (considered a social adaptive system) from falling into a state of equilibrium (where knowledge becomes a barrier to instead of a driver of

innovation) by creating path dependency (Carlile, 2004; van, 2000). Therefore, in a situation in which designers are intended to create innovations it makes more sense to facilitate efficient and productive interaction across boundaries than to attempt to remove boundaries. Two central approaches for supporting collaboration across boundaries in a multidisciplinary team are the use of boundary objects and the use of knowledge brokers.

Knowledge brokering is a concept used by Wenger (1999) and others in the "communities of practice" theory. Brokering is boundary spanning performed by humans with dual membership in communities, where the community is the embodiment of a knowledge domain. The broker performs boundary leadership, which is the task of keeping two communities connected. Through brokering, elements of one domain (e.g., know-how) are transferred to another. When members of communities enjoy dual membership, brokering does not automatically occur because something must be transferred if the activity is to be designated as brokering; potential brokering is often hindered by factors such as social status and seniority. The broker will often bring crucial knowledge to the different networks to which he belongs; however, brokers are often not fully accepted by the communities they connect. Wenger (1999) states that the main challenge of brokering is the challenge of avoiding the two opposing tendencies of being pulled into full membership and being rejected as an intruder.

The term 'boundary object' is commonly used by sociologists in knowledge management (see, e.g., ((Star, 1989); (Carlile, 2002; Wenger, 1999)). A boundary object is an entity capable of facilitating the transfer of knowledge across a boundary defined by knowledge domains (e.g., blueprints facilitating knowledge transfer between engineers and the workshop). The concept relates to the brokering concept from communities of practice as it represents the objectification of the brokering activity by facilitating the movement of elements from one practice to another. Star (1989) describes boundary objects as objects that work to establish a shared context that 'sits in the middle' and can be categorised as repositories, standardised

4

forms and methods, objects or models, and maps of boundaries. Carlile (2002) and Wenger (1999) proposed collapsing the last two categories into one, namely objects, models, and maps, as the differences between them in practice are negligible (see Table 2). The three categories of boundary objects primarily address one of three associated boundaries, i.e., syntactic, semantic and pragmatic boundaries. By analysing these three types of boundaries, a set of characteristics and an associated knowledge process that distinguishes an efficient boundary object can be formulated (see Table 3). It should be noted, however, that a central role of boundary objects, is to establish and act within a boundary infrastructure in which boundary objects interact within the context in which they are used by individuals and also interact with other boundary objects in the same infrastructure. E.g., the repositories and standard forms support the use of objects, models and maps by users.

Table 2 Boundary object categories

Category	Description	Boundary	Reference
Repositories (e.g., CAD parts libraries)	Common reference point and resource for data, measures, or labels across functions that provide shared definitions and values for solving problems.	Syntactic	(Carlile, 2002; Wenger, 1999)
Standardised forms and methods (e.g., EC forms)	Shared format for solving problems across different functional settings. Forms come in a mutually understood structure and language.	Semantic	(Carlile, 2002; Wenger, 1999)
Objects, models, and maps (e.g., sketches and Gantt charts)	Simple or complex representations that can be observed and then used across different functional settings. Objects, models and maps depict differences and dependencies identified at the boundary on multiple levels.	Pragmatic	(Carlile, 2002; Wenger, 1999)

Table 3 Characteristics of effective boundary objects

Boundary	Description	Process	Reference
Syntactic	Establishes a shared syntax or language for individuals to represent their knowledge.	Knowledge transfer	(Carlile, 2004)
Semantic	Provides a concrete means for individuals to specify and learn about their differences and dependencies across a given boundary.	Knowledge translation	(Carlile, 2004)
Pragmatic	Facilitates a process where individuals can jointly transform their knowledge.	Knowledge transformation	(Carlile, 2004)

One example of a boundary object commonly used by design teams is prototypes of the product, which among other functions, enables engineering designers to address manufactur-

ing concerns in collaboration with production engineers. The prototype creates a tangible common ground for discussing manufacturing issues, e.g. quality and tolerances.

Despite the consensus on the need for high-quality boundary spanning to integrate knowledge across boundaries and on its substantial effect on the performance of design teams, there is a lack of research on the testing of concrete support methods for boundary spanning in design teams charged with creating technological innovation. Therefore, the research question guiding this paper is the following:

How may the spanning of boundaries that are caused by knowledge asymmetries in multidisciplinary design teams be supported during innovation projects?

To address this question, a support method for spanning boundaries (referred to as Ensight) was developed using a participatory design process and subsequently implemented and tested in a Danish energy utilities company. This paper reports the results of the testing of this support method both in practice and in an experimental setting.

1   Research Methodology

This study was part of a larger research project examining how to support designers in their work with multi-level innovation in the energy sector, i.e., creating concepts for the transition of energy utilities from technologies based on fossil fuels to sustainable technologies. One of the central challenges faced by both managers and designers was observed to be the integration of knowledge across highly diverse domains (e.g., energy resource assessments, regulatory frames and user insights), as the domains changed in unpredictable ways, and several different domains were always present in the innovation projects (Jensen et al., 2011).

The larger research project was designed according to the four-step design research methodology (DRM), i.e., clarification, descriptive study I, prescriptive study, and descriptive study II (Blessing & Chakrabarti, 2009). This particular study reports the results of the descriptive

study II step, which involves evaluation of the prescribed support, for the dual purposes of validating the analysis and confirming the value of the proposed support in industrial use (Blessing & Chakrabarti, 2009); (Cross, 2007). Consequently, this study was designed with a research-based prescription as the starting point and focused on explaining whether and why the prescription works as a method for supporting design in multidisciplinary teams (see Figure 1). For the testing stage, two approaches were used. The first approach consisted of 35 structured interviews with test subjects in the case company; the second approach involved evaluation of 37 concepts created in controlled experiments with 22 post-graduate students and researchers. At this stage, Ahmed & Wallace (2004)'s extension of Kirkpatrick (1979)'s framework for testing the effect of human resource training was used. In the interpretation stage, the boundary object framework was used to explain the test results in terms of how the research-based prescription works and/or fails.
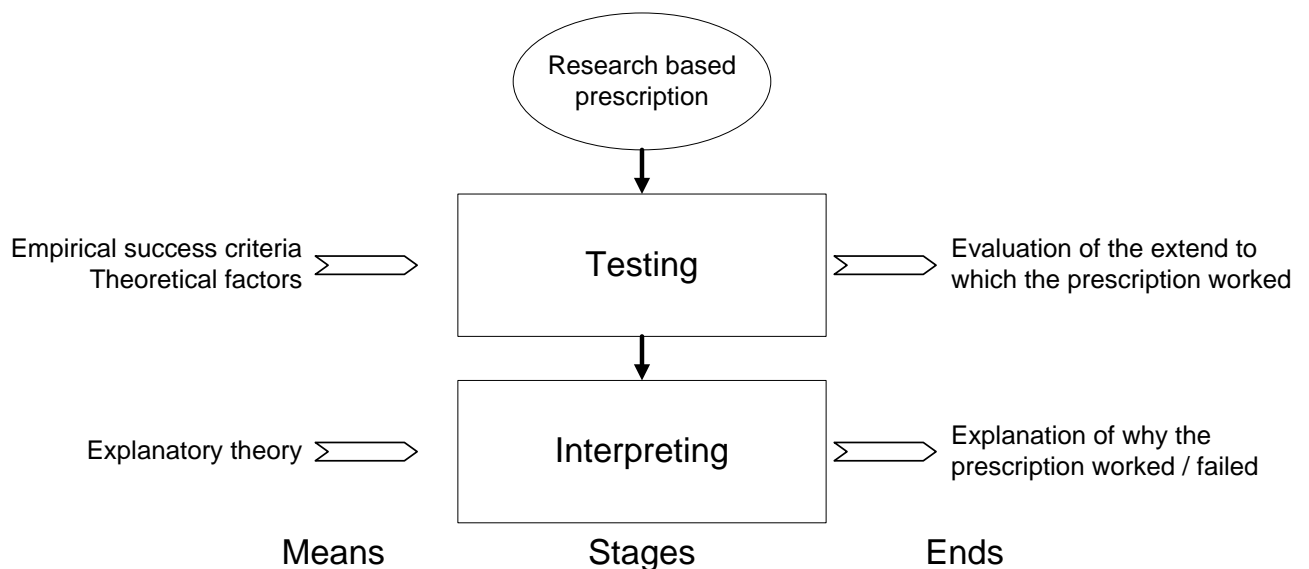
Figure 1 Overview of the research design for testing a research-based prescription

Table 4 Evaluation framework

Level	Definition	Main approach	Reference
Validation	Validation aims to determine whether the content of the method is appropriate for the goal it is supposed to address and whether it creates the predicted outcomes.	Interviews	(Ahmed & Wallace, 2004)
Reaction	Reaction may best be defined as how well the trainees liked the particular training program. Evaluation in terms of reaction is the same as measuring the feelings of the conferees.	Interviews	(Kirkpatrick, 1979)
Learning	Learning is defined in a rather limited way as follows: What principles, facts and techniques were understood and absorbed by the conferees?	Interviews	(Kirkpatrick, 1979)
Behaviour	On-the-job application of the principles, facts, and techniques that were learned by the conferees during the training program.	Interviews	(Kirkpatrick, 1979)
Results	The objective of most training programs can be stated in terms of results desired. These results can be classified as follows: reduction of cost, reduction of turnover and absenteeism, improved product quality, etc.	Controlled experiment Interviews (secondarily)	(Kirkpatrick, 1979)

The evaluation framework (see Table 4) was used together with the boundary object theory to guide the creation of the interview questions. Thereby, the evaluation framework served as a framework for evaluating the extent to which Ensight fulfils its purpose as a boundary object. This model has been widely used for evaluating methods, tools, and training programmes in academia and industry (Ahmed & Wallace, 2004). The most challenging level to assess from this framework is the "results" level, as improved results will often take a long time to materialise and cannot be easily captured through interviews (Kirkpatrick, 1979). Therefore, a controlled experiment was conducted to provide an adequate method to assess the "results" level.

1.1   The prescription: Ensight

Ensight is a serious simulation board-game developed by the authors in collaboration with DONG Energy's innovation centre as a support method for multidisciplinary design teams. It is based on a longitudinal descriptive study of innovation within the Danish energy utilities company DONG Energy.

The development of Ensight was done through a participatory design process in three steps, starting with step 1, the identification of requirements from the descriptive study, which can be summarised in four categories: 1) Ensight should create a common frame of understanding among the design team members who are from multiple knowledge domains collaborating on innovation projects; 2) Ensight should provide technically minded engineering designers with a deeper understanding of how value is created in the electricity market; 3) Ensight should establish a platform for the rapid education of new team members with little to no prior knowledge of the heavily regulated energy sector; and 4) Ensight should provide insight into the technical constraints of the electricity market for people with a business background. In step 2, different concepts for addressing the requirements were explored in close collaboration with the case company. Initial solutions included an idea-storming platform with a built-in knowledge translation and structured informal networks. The board-game format was decided upon due to its strong fit with the requirements, ability to embed various knowledge domains, and possibility for creating and enforcing rules for social interaction. In step 3, the details of Ensight were designed through an iterative approach where stakeholders involved in designing the Danish energy market, senior researchers from the Danish national energy laboratory, and specialists from DONG energy were involved. A total of six iterations were made on the game based on feedback from these stakeholders, who all played early prototypes of Ensight. This approach served to ensure the internal validity, i.e. the correctness of the content, as well as extensive implementation. The result from this process was a board game, which simulates the energy-market with the interdependencies among market mechanisms, operations, research and development, and regulatory frames.

The game takes approximately 1½ hours to play, and the objective of the game is to become the most profitable energy utilities company through a combination of trading, regulatory work, and technological innovation in a limited part of the energy value-chain (see Figure 2).
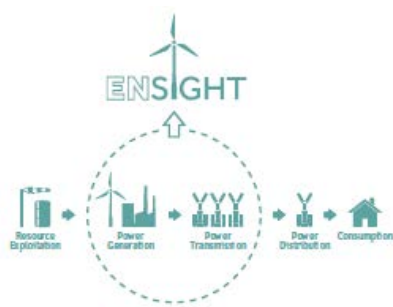
Figure 2 Left: The energy value chain, Right: description of Ensight given to participants

Simulation games have the benefit (over the discourse-games more commonly used by human resource professionals) that concrete knowledge can be embedded and that the participants solves a concrete task together, which has been shown by e.g. Bechky (1999) and Okhuysen & Eisenhardt (2002) to be an effective mechanism for knowledge integration. A common example of a simulation-game is monopoly, in which the real-estate market is simulated. Furthermore, board-games has the benefit over e.g. card-games and computer games, that the board becomes a common point of focus, thus facilitating what Helper *et al.* (2000) referred to as a joint effort to integrate knowledge in the context of a concrete issue. In order to provide concrete and relevant issues to the participants, Ensight is built specifically on knowledge relevant for the energy-sector gathered through a no. of independent studies (Jensen et al., 2013a; Jensen et al., 2013c) and can be likened to monopoly. Only, instead of trading and developing land, the participants trade, develop and operate energy assets, such as wind-turbines and hydro-plants. Ensight follows a flow where all participants are kept active all the time through following the activities seen in Figure 3 in each turn of the game, in order to ensure a common point of focus and involvement of participants in solving joint issues. Four categories of playing cards are used to mimic changes to external conditions around the company and the potential internal responses to these. The categories consist of legislation, research and development, construction, and operation. These cards are distributed through a

system of drawing and buying cards in every round during the game. Examples of these cards include; increased oil-prices, due to depletion of reserves and responses in terms of high-efficiency fossil technologies and development of alternative energy solutions. A complete interactive walk-through of game and scenarios is found at www.Ensightweb.dk (Jensen et al., 2013b) (username: journal; Password: Ensight).
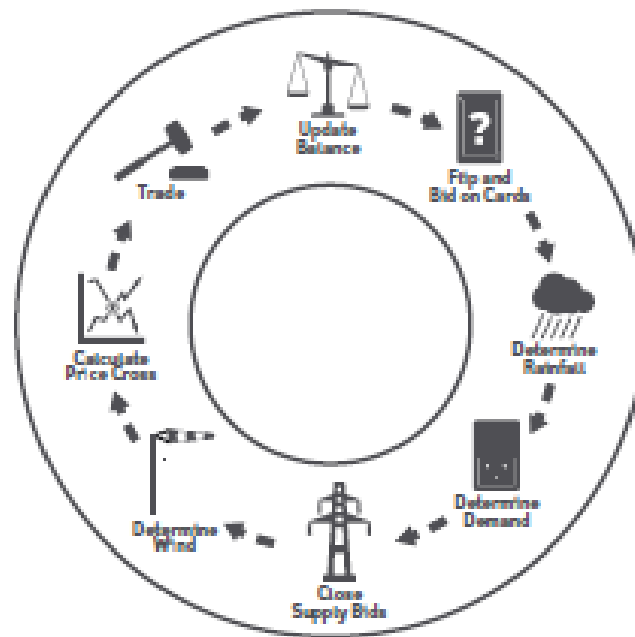
Figure 3: Activity wheel from Ensight

Instruction for the use of Ensight during the controlled experiment and in the case company, before the interviews, was carefully scripted in advance to achieve the fewest deviations in execution possible: Firstly, the participants were trained in the game by playing a round that was simplified and played without the cards to introduce the game mechanics. The next round would then be the first real round out of a total of 1½ hours playing time. Secondly, during the game, the participants would play a carefully prepared scenario called "blue globe" which is a plausible balanced scenario where neither green nor fossil energy is given any specific advantage. The scenario was created through pre-sorting the cards so that they would occur in the same way in all games and thus ensure comparable conditions for the ex-

periments. Furthermore, all the participants were playing in teams of two and the teams mixed technical specialists with market specialists.

1.2 Collection and analysis of interview data

In total, Ensight was played with more than 100 employees in DONG Energy over a period of 6 months. From this population, 35 people who had participated in a game session between 2 and 12 weeks previously were randomly selected for structured interviews, which each lasted between 20 and 30 minutes. Conducting the interviews less than 12 weeks after the Ensight game improves the likelihood that informants remember the event accurately (Huber & Power, 2006), while waiting at least two weeks allows for changes in behaviours to manifest themselves and immediate false optimism to settle.

The interview guide was based on (Ahmed & Wallace, 2004)'s evaluation framework, theory of boundary objects, and was adapted to the context using the insights gained from running the game sessions (see Table 7). The questions on reaction were focused on indicators for immediate reaction e.g., whether the benefit is worth the time required to play the game. Learning was focused on specific concepts, e.g., understanding how value is created in the market. Behaviour focused on positive boundary spanning changes in the interviewee's behaviour after the game. The results were focused on direct boundary spanning effects from Ensight, in terms of the ability of Ensight to deliver a certain result, together with an assessment by the interviewee of the importance of the particular result. In validity, the focus was on whether the interviewee was able to use the game, as an essential feature of a boundary object is the ease by which it connects to actors in the domains it spans. The questions were further connected to the analytical frame as shown under topics in Table 5, where each dimension of a boundary object is connected to its respective questions, e.g. the syntactic boundary to the questions concerning shared syntax.

During the interviews, the interviewer asked the interviewee to rank the questions on a 7-point Likert scale or answer 'I don't know' (see Table 6). At the end of each interview topic, the interviewee was given an opportunity to provide a short qualitative statement. The interviewees were part of DONG Energy's innovation function and were from four different departmental backgrounds (see Table 5). Using interviewees from 4 different functional departments and across several hierarchical levels improves the robustness of the results by reducing informant bias, while sampling within one firm but across departments has the advantage of controlling for organisation-level factors, such as corporate culture, which may affect the results (Martin & Eisenhardt, 2010). All the interviews were conducted by the same person and were conducted face-to-face in the interviewees' office or meeting rooms, under complete confidentiality and anonymity.

Table 5 Overview of interviewees

Department	Amount	Represented Titles
Innovation Centre	13	Partnership manager, innovation manager, graduate, senior innovation manager, IPR specialist, strategy advisor
Business Strategy	8	Graduate, senior consultant, lead market analyst, economist, lead strategy consultant, model developer
Wind and thermal R&D	11	R&D manager, lead model developer, model manager, engineer, specialist, regulatory advisor, graduate, business analyst
Sales and Distribution Innovation	3	Graduate, head of innovation, model developer

Table 6 Likert scale used for the scoring of interview questions

Score	1	2	3	4	5	6	7
Rating	None	Little	Little to moderate	Moderate	High to moderate	High	Very high

Table 7 Topics and examples from the interview guide

Topics	Question no.	Questions with shortened sub-questions
Reaction[26]	1 2 3	• After playing Ensight, would you consider serious games as a good way to learn about complex topics, such as the energy market? • To what degree would you consider the time spent on Ensight worthwhile? • How likely is it that you would use Ensight again with other people?
Learning[26] Syntactic boundary (Carlile, 2004)	4 5.1–5.6	• Did you feel that Ensight provided you a better understanding of some of the fundamental concepts in energy markets? • How would you rate the change in your understanding of the following concepts: Value creation, price cross-formation, external effects of decisions, impact of regulatory changes, impact of market changes, impact of R&D.
Behaviour[26] Syntactic boundary (Carlile, 2004)	7.1–7.3	• After having played Ensight, are you then likely to focus more on the following factors while 1) starting or supporting external networks, 2) starting or supporting internal projects and/or departments, and 3) Starting or supporting networks: o Create common language, ensure consistent perception of concepts, ensure consistent perception of future scenarios, and use Ensight as support.

Results[26]
 	
Semantic Boundary (Carlile, 2004)
 	
Pragmatic boundary (Carlile, 2004)
	8.1–8.4
	13
	14
	15
		• How valuable, if at all, would you assess Ensight to be for accelerating the education of prospective partners in value creation in the energy sector?
		• How valuable, if at all, would you consider Ensight to be for team building activities?
		• How valuable, if at all, would you consider Ensight to be for "quick and dirty" energy scenario analysis?
		• Rate Ensight's ability to deliver the following, as well as the importance of them:
		  o Creation of a common language between novices and experts in energy
		  o Creation of a common interpretation of the language used between people
		  o Creation of a common understanding of the future and how it impacts the energy sector
		  o Allowing outsiders access to our (Dong energy) world, thus letting them challenge our beliefs and assumptions in the energy sector?

Validation[26]	9 10 11	• How easy or hard would you consider it to integrate Ensight as a tool in DONG Energy A/S business units? • How easy or hard do you find it to participate in Ensight? • How easy or hard do you find Ensight to be for people with other backgrounds than energy technology?

The interviews were all analysed using simple descriptive statistics, which was made possible by using Likert scales for all the questions, where 1 was considered an absence of the effect, 4 was considered moderate, and above 4 was considered high. Confidence intervals based on standard error calculations of the means were used to indicate whether the answers to questions were conclusive in terms of placement on the scale. The responses were further analysed qualitatively using the comments that respondents were allowed to make during the interviews. These responses proved especially valuable in explaining outliers. Finally, the findings from the analysis were interpreted through the framework of boundary objects to explain the effects measured with the interviews.

1.3 Collection of experimental data

From an evaluation standpoint, Ensight should ideally be measured directly in terms of the results achieved, such as reduction in product cost, quality of product concepts, or improved team productivity. However, these results are very difficult to measure reliably, especially because the effect from the support is difficult to separate from the other factors that affect the desired results (Kirkpatrick, 1979). This challenge increases significantly when performing evaluation studies in an industrial setting as the number of uncontrollable factors is higher than in an experimental setting. Therefore, a controlled experiment was established to test the effects of Ensight on the fourth level in Kirkpatricks adapted framework "results" by using an operational definition of results as concept quality based on empirical data on criteria for assessing concept quality from the case company. A total of 22 post-graduate students and early researchers in business and engineering were used as test subjects to create a total of 37 product concepts for comparison. The experiments were conducted over two periods, one at Stanford University in California and one at the Technical University of Denmark (DTU). In both studies, the experiment lasted three hours. Both experiments were conducted according to the same predefined protocol, first at Stanford University and later repeated at DTU (see Table 8)

Table 8 Details of the experimental set-up

	Stanford		DTU	
	Ensight group	**Control group**	**Ensight group**	**Control group**
Introduction	5 minutes			
Team formation	10 minutes			
Design task 1	30 minutes			
Ensight	90 minutes	15 minutes (break)	90 minutes	15 minutes (break)
Design task 2	30 minutes			
Team size	2 people/team			
Number of teams	3 teams	3 teams	3 teams	2 teams
Disciplines in teams	Business management Engineering design	Business management Engineering design	Electrical engineering (business development) Engineering design	Electrical engineering (business development) Engineering design
Facilitation	Researcher	Researcher	Trained facilitator	Trained facilitator
Data collected	Concept descriptions Design questions			

To measure changes in performance before and after Ensight, two almost identical design tasks were created. The participants were given a written task asking them to create design questions and concepts for introducing electrical cars to private consumers. They were also provided with a document with a description of the user segment on which they were to focus. The only difference between design task 1 and design task 2 was which user segment the participants were focussed on. Both segments were selected from the early and late majority on (Rogers, 2003)'s curve of technology diffusion to avoid extreme cases affecting the performance. The description of the segments originated from an anthropological study performed by DONG Energy called the Etrans project, thus increasing the direct connection between interviews and experiment further. Between the two tasks, the Ensight-group were playing the scripted game as described earlier and the control group were given 15 minutes coffee break, in which they were allowed to interact informally with the other control group teams. The reason for this interaction was to allow for some baseline reflection, as the teams from the Ensight group would inevitably be interacting with each other during the game.

1.4   Analysis of experimental data

In analysing the data from the experiment, a central challenge was to create a reliable and operational definition of how to measure the quality of a concept. This analysis was performed through a qualitative case study in DONG Energy, where the coverage of ten specific knowledge domains of a concept was observed to be directly associated with the perceived concept quality of designers and decision-makers and used to make go/no-go decisions i.e. decisions on whether a concept would be allowed to go from front-end to formal product development (Jensen & Ahmed-Kristensen, 2010). These ten domains were validated separately in a workshop with designers and decision makers in DONG Energy; thus they are considered to be a reliable measure (see Table 10). It should be noted, though, that this measure is not a global definition of concept quality but rather a local definition of perceived concept

quality, evaluated in terms of a concept's likelihood of being approved through DONG Energy's formal and informal decision processes.

The causes and effects in the experiment are described using a model in which the *concept quality* and *knowledge-domain coverage* of a concept are co-varying latent variables, meaning that they affect each other but cannot be measured directly (see Figure 4). The Ensight treatment is measured as a binary factor, and the knowledge domains are discrete, observable variables measured on a scale from 1 to 7. Each of these measures is affected by other latent variables, aggregated into the measurement error, which is indicated by δ. The hypothesis states that if Ensight is used, the concept quality increases measurably in one or more of the 10 knowledge domains.
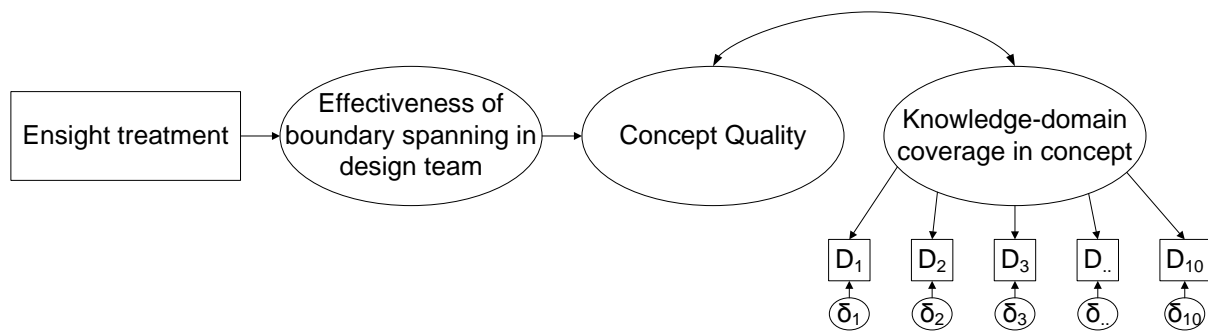
Figure 4 Measurement model for the effect of Ensight on concept quality (D_1-D_{10} = observable variables, δ_1- δ_{10} = measurement error)

The concepts generated by the teams were visualised in spider diagrams and analysed for significant variance. In this manner, it was possible to compare the quality of the concepts generated in design task 1 and design task 2 by Ensight and control group. The comparison was performed with coverage as one criterion, i.e., the total number of knowledge domains addressed in the concept, and depth, from 1 to 7, as the second criterion, i.e., the extent to which each of the knowledge domains is addressed by the concept (see Table 9). All the concepts were evaluated by the researcher. The design questions were used to provide the rationale be-

hind concepts, which significantly improved the quality of the coding as the questions pro-

vided richer information about the concepts and, therefore, a more accurate rating.

Table 9 Scale used for the scoring of knowledge domains

Score	1	2	3	4	5	6	7
Rating	No depth	Little depth	Little to moderate depth	Moderate depth	High to moderate depth	High depth	Very high depth

Table 10 Knowledge domains used for estimating concept quality

Domain	Definition
Business model and processes	How to develop the idea or technology into an appropriate business concept
Development funding	Knowledge on how to fund a project to develop the ideas or technologies at hand
Internal alliance creation	The political process by which internal support for ideas is generated
External alliance creation	Knowledge about how support, e.g., visions through alliances with universities
Regulatory environment	Process knowledge on how regulatory frame affects ideas/can be affected
Insights into user's world	Knowledge about the behaviour of users and the reciprocal effects on innovations
Dynamics of the market	Macro-scale market insights about market forces, entry barriers, and fluidity
Technical characteristics	Micro-level knowledge about the characteristics of the specific technology at hand
Synergies with energy system	Macro-level energy system: Interactions between elements in the power grid
Energy resource reliance	Insights into a strategic energy resource future, e.g., biomass sourcing or wind

2 Findings

The effect of the boundary object (Ensight) as a support for multidisciplinary design teams

was evaluated based on the outcome of the interviews with 35 people and the experiment

with 22 people. The interviews cover all five levels in the evaluation framework, whereas the

experiment provides an in-depth view of the "results" level in the framework. Ensight was

observed to have a moderate or higher effect on all five levels and to significantly increase

concept quality. The analysis of the interviews and the experiment is performed separately, as

the data are of different nature, and the outcome of the interview analysis is presented first,

followed by the analysis of the experiment.

2.1 Interviews

From the analysis of the interviews with designers who had used Ensight in their company, the designers were observed to have reacted positively to Ensight, learning key concepts from other domains through the game, positively changing their behaviour, and considering Ensight to have helped them to collaborate better in their teams by helping them span syntactic, semantic and pragmatic boundaries. The chart in Figure 5 presents the individual scores of the questions, and the bars indicate the standard error at each level.
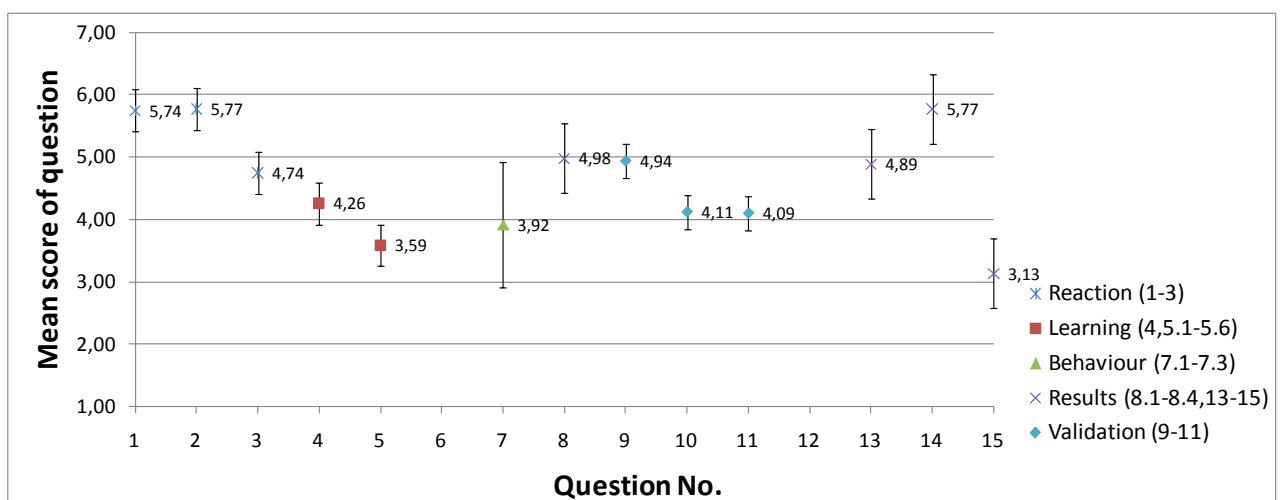
Figure 5 Error bar chart of scores for the interview questions, 1= no effect 7= very high effect.

The mean scores on the 7-point Likert scale of each of the 15 questions posed to the interviewees are presented in Figure 5. Questions 1 through 3 evaluated the interviewee's immediate reaction, e.g., whether it had been worth the time the game took; with mean scores between 4.74 and 5.74, the reaction was highly positive. Question 4 evaluated learning in general, and question 5 evaluated the interviewees' learning based on specific concepts, e.g., an understanding of how value is created in the market. Here, the interviewees scored Ensight between 3.59 and 4.26, which indicated that significant general learning and learning in the key concepts had taken place. Question 7 evaluated positive boundary spanning changes in the interviewee's behaviour after the game. A mean score of 3.92 was achieved based on evaluating three scenarios: starting or supporting external networks, starting or supporting in-

ternal projects and/or departments, and starting or supporting networks, which indicates significant behavioural improvements. Question 8 and 13 through 15 evaluated the results by focusing on direct boundary spanning effects from Ensight, in terms of the ability of Ensight to deliver results such as a common language between participants. With scores between 3.13 and 4.98, Ensight is demonstrated to deliver concrete results. Questions 9 through 11 evaluated validity in terms of the ease of Ensight to connect to actors in the domains it spans. The scores fall between 4.09 and 4.94, indicating that Ensight is a valid boundary object. Questions 6 and 12 were qualitative questions and thus have no score in Figure 5. From these results, it was observed that the mindset of the participant, i.e., serious simulation game or fun entertainment, was a likely explanation for the low scores (mean < 2.5) of Ensight by four of the interviewees. These interviewees explained that they had entered the game thinking about it as a fun teambuilding exercise and were then surprised by the complexity and hard work it required. In addition, it was observed that a group of participants who rated the learning lower than average did so because they possessed deep knowledge about the concepts before the game as a part of their professional knowledge. However, several of these participants commented that the people they had been playing with had learned a lot, which had supported their further collaboration.

These results suggest that Ensight is generally rated positively across all levels of evaluation, which is further supported by the overview in Table 11, where the mean score at each level is calculated and compared with the rating. All five levels are observed to be rated as moderate or higher.

Table 11 Evaluation of results from the interviews

Evaluation levels	Associated questions	Mean	Rating (all positive)
Reaction	1, 2, 3	5,42	High to moderate reaction
Learning	4, 5.1–5.6	3,92	Moderate learning
Behaviour	7.1–7.3	3,92	Moderate behaviour
Results	8.1–8.4, 13, 14, 15	4,69	High to moderate results
Validation	9,10,11	4,38	Moderate validity

As a supplement to the analysis across evaluation levels, an analysis across the interviewees was performed to estimate the general satisfaction of the participants with Ensight as a boundary object (see Table 12).

Table 12 Distribution of interviewees based on their discrete mean ratings

Interviewee's scoring	1 None	2 Little	3 Little to moderate	4 Moderate	5 High to moderate	6 High	7 Very high
Interviewees	0 (0.0 %)	4 (11.4 %)	9 (25.7 %)	5 (14.3 %)	10 (28.6 %)	7 (20.0 %)	0 (0.0 %)

By comparing the mean ratings of the interviewees across all the questions, it is observed that the majority of interviewees place Ensight between 3 and 6, with 11.4 % placing it with a mean score of 2, and 20% with a mean score of 6. With a score of 1 equalling nothing gained from Ensight and 2 equalling little gained, 88,6 % of the interviewees scored Ensight as having provided *little to moderate* or higher gains, thus indicating that the majority of participants generally perceived the game to have had a positive effect on their work within multi-disciplinary design teams.

Seen from the perspective of crossing domains boundaries, the positive responses to questions addressing all three boundaries implies not just a temporary attention to collaborating, but, also a long term in interest in continuously addressing the gap, seen e.g. in the answers to questions 7.1 through 7.3 where it is observed that several weeks after using the boundary object, participants still show increased attention to creating common syntactical and semantic perceptions. This has been described by Cagan & Vogel (2002) as the perceptual gap, i.e. the difference in perspective between team members, stemming from education, personality etc. This gap is a barrier for collaboration as well as a driver for innovation. Thus, it can be observed that a boundary object can contribute to appreciation of other perceptions, which are essential to creating novel designs. The long term attention to this and to creating joint per-

ceptions of visions are mechanisms that make the boundary objects contribute to improved design results.

2.2   Controlled experiment

In the experiment performed with postgraduates and early researchers, the concepts produced by the design teams were analysed according to the coverage of the ten knowledge domains, scored on a scale from 1-7 indicating the depth each domain. The controlled experiment was established to directly address the fourth level in the evaluation framework (results), which is inherently challenging to address through interviews. Thereby, the controlled experiment especially adds to understanding the effects and mechanisms of pragmatic and semantic boundary crossing and to a smaller extent to that of syntactic boundary crossing (see Table 7)

The analysis of the experiment was performed at two levels: first, the aggregated improvements were analysed across the ten domains of knowledge, and second, the distribution of improvements was analysed across the ten domains.

The first level of analysis was a comparison between the scores averaged over all concepts and all teams but separated between the control group and the Ensight group, as well as between the repetitions, i.e., the DTU and Stanford tests (see Table 13). The *Δ score* result indicates differences in the depth and/or coverage between the two tasks.

Table 13 Total scores of control groups and Ensight group in the two repetitions

	Control group		Ensight group	
	Quality	Quantity	Quality	Quantity
Mean Score Task 1	22.29	7	18.83	8
Mean Score Task 2	23.83	6	25.38	16
Δ Score	1.54 (6.9 %)	-1	6.56 (34.8 %)	8

The comparison indicates that the effects occurring from natural learning, which is indicated by the control group scores, are significantly lower than the differences in scores observed for the Ensight group. In the control group, a *Δ* score of 1.54 is observed, corresponding to a

6.9% improvement, while the Δ score of the Ensight group is 6.56, corresponding to a 34.8% improvement. Regarding quantity of concepts, it is observed that the control group has no significant change in their output, whereas the Ensight group doubled their output of concepts.

Thus, a positive effect of Ensight was observed that appears to outweigh natural learning effects from repeating tasks twice; however, a second level of analysis is needed to explore the distribution of change between specific knowledge domains and establish whether these are indeed significant changes.

An analysis of variance of each domain within the control group and the Ensight group was carried out to establish significance of changes (see Table 14). In the analysis, a single factor (Ensight) is tested on two levels (0 and 1), with $\alpha = 0.05$.

Table 14: Results from single-factor two-level ANOVA for each domain and group

Domain	Groups	Ensight test group (alpha 0,05)				Control group (alpha 0,05)			
		MS	F	P	Fcrit	MS	F	P	Fcrit
Business model and processes	**Between**	**24,083**	**6,551**	**0,018**	**4,301**	0,090	0,032	0,861	4,844
	Within	**3,676**				2,803			
Development funding	Between	0,021	0,489	0,492	4,301	0,066	0,846	0,377	4,844
	Within	0,043				0,078			
Internal alliance creation	Between	0,188	0,489	0,492	4,301	0,000	-	-	-
	Within	0,384				0,000			
External alliance creation	**Between**	**24,083**	**5,004**	**0,036**	**4,301**	0,808	0,413	0,534	4,844
	Within	**4,813**				1,955			
Regulatory environment	Between	1,021	0,577	0,456	4,301	0,007	0,002	0,968	4,844
	Within	1,770				4,251			
Insights into user's world	**Between**	**4,688**	**5,205**	**0,033**	**4,301**	2,374	1,142	0,308	4,844
	Within	**0,901**				2,078			
Dynamics of the market	Between	0,188	0,653	0,428	4,301	0,016	0,012	0,915	4,844
	Within	0,287				1,383			
Technical characteristics	**Between**	**20,021**	**4,797**	**0,039**	**4,301**	0,007	0,002	0,961	4,844
	Within	**4,173**				2,978			
Synergies with energy system	Between	0,083	0,188	0,669	4,301	0,029	0,012	0,915	4,844
	Within	0,443				2,459			
Energy resource reliance	-	0	-	-	-	0	-	-	-

In Table 14, it is observed that significant changes in the design teams' performance occurs in four dimensions (highlighted in grey) after having used Ensight, whereas no significant change is observed in the control group. The two domains *business model and processes* and

technical characteristics were specifically addressed in the requirements for developing En-

sight and the improved performance on these dimensions indicates a stronger integration be-

tween business knowledge and engineering knowledge, as was intended. From the perspec-

tive of boundary objects, integration of these domains into concrete concepts points to a suc-

cessful crossing of the pragmatic boundary. This is an important finding as it shows that

boundary objects can be designed to deliberately address integration of specific knowledge

domains in design teams and thereby decrease as well as promote fixation of designers on a

limited set of domains. The increase in *External alliance creation* domain is likely to be

caused be the systemic simulation perspective inherent in Ensight and indicates that boundary

objects with simulation capabilities can be an effective way of encouraging a more systemic

focus in product concepts. Ensight, was designed to only cover the centre of the energy val-

ue-chain (see Figure 2) thereby excluding primary resources and end-users. While the domain

energy resource reliance" is completely unchanged as expected, this is not the case for *in-

sight into users' world*, which has improved significantly. The design task requires the partic-

ipants to consider insight into user's world, however the significant increase in its integration

in the Ensight group was unexpected. One explanation for this is that common knowledge is

generated through the design-teams interaction with the boundary object, which then acts as

an integrative mechanism for domains not specifically addressed by the object. Common

knowledge (across different domains) is widely accepted as a mechanism for integrating

knowledge from different domains, also the domain-knowledge that is not common (Dixon,

2000; Grant, 1996). However, the creation of common knowledge has commonly been asso-

ciated with e.g. individuals performing work-related tasks together over period of time or

having similar educations. These results indicate that common knowledge can be created in a

simulated environment facilitated by a boundary object. Thus, boundary objects are likely to

have long term effects on knowledge integration, also objects is no longer in use.

In Figure 6, the depth and coverage of knowledge domains are visualised using spider web diagrams.
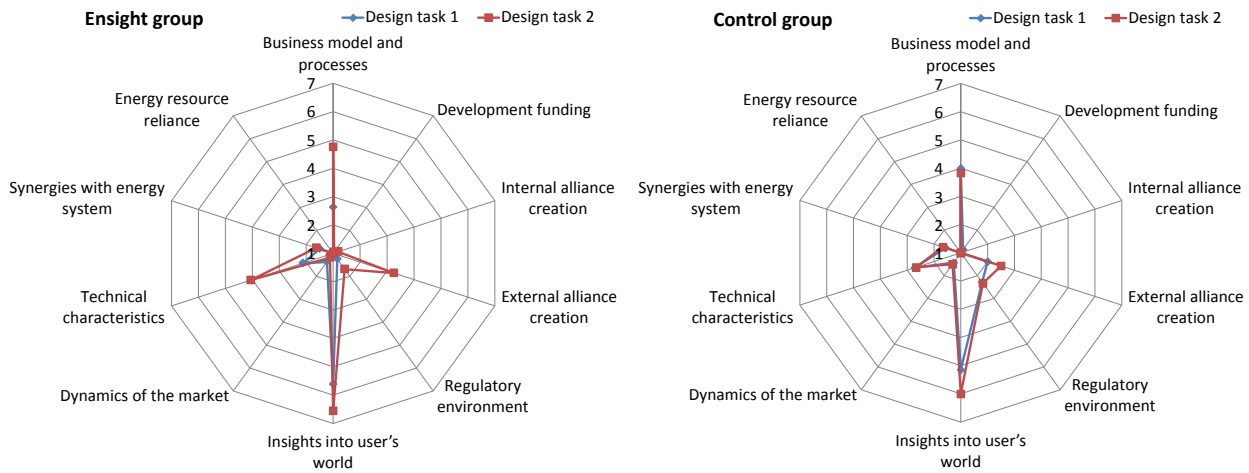
Figure 6 Average coverage and depth of knowledge domains by test and control group

In terms of coverage, the diagrams show new knowledge domains being integrated into the concepts developed in task 2 by the Ensight group. In contrast, there was not such introduction of new knowledge domains seen in the control group. Furthermore, it is observed that the use of Ensight facilitated integration of widely different knowledge domains, while at the same time leaving a number of domains where no change is seen. From the perspective of boundary spanning, this indicates that Ensight was addressing boundaries between domains and not just teaching them and also the Ensight itself belonged to a number of specific domains. Thereby, at least this type of boundary object is less likely to be generically facilitating knowledge integration across any domain, but bound to some extent to the specific domains considered in its design i.e. in this case innovation in the energy sector. However, the common knowledge created can later support integration across a further set of domains.

3 Discussion

Ensight was observed through the interviews to be positively received by 89% of the interviewees and to address the issue of spanning boundaries with a moderate-to-high rating on all levels in the evaluation framework. Concerning the results, the interviews revealed significant improvements measured on functional properties commonly related to boundary objects, i.e., the ability to address syntactic, semantic and pragmatic barriers. In the controlled experiment, the effect of Ensight on the results was measured by evaluating the output from the multidisciplinary design teams i.e., the concepts that they created. Ensight was observed to positively affect depth, and the diversity of knowledge domains covered in the product concepts. To understand the role Ensight played in the multidisciplinary teams, an explanation based on boundary object theory is discussed here.

From the interviews, evidence was especially found for the spanning of syntactic and semantic barriers by Ensight via, e.g., questions 4-6, which evaluated learning through the understanding of concepts that were observed to be essential for the shared syntax, such as *price cross.* Question 8 was a further measure of syntax by directly addressing the ability of the creation of a common language, and it also measured the semantic barriers by questioning Ensight's ability to support common interpretations between actors. The high ratings of the questions indicate that these boundaries were in fact spanned by Ensight.

The controlled experiment in particular provided evidence for the spanning of pragmatic boundaries through the increased integration of different knowledge domains shown by the significant increase in performance of the Ensight groups compared to the control groups. This finding indicates a spanning of the pragmatic boundary, as joint transformation of knowledge between team members in the multidisciplinary teams is likely to have caused an integration of the diverse domains into the shape of design concepts. The significant improvements observed in these concepts also indicate that the spanning of boundaries does in-

deed lead to a higher quality of designs, measured by the coverage and depth of diverse knowledge represented in the concept. With respect to the quantity of concepts, the use of a boundary object support resulted in a 100% increase in the number of concepts created, from 8 concepts without support to 16 with the support. Through these boundary spanning functions, Ensight enables participants from different domains to experience how dependencies across domains will play out in the event of changes to, for example, a company's technological base, market position, innovation strategy, or regulations.
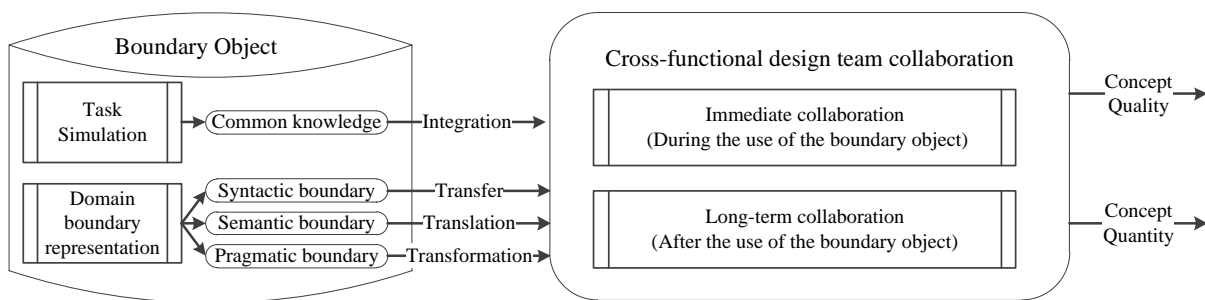
Figure 7: Observed effects of a boundary object on design team collaboration

The functions were embedded into the elements of Ensight's physical structure, much in the same way that functions of a product are performed by its physical structure (see Table 15) The physical structure of Ensight was designed according to the design strategy described earlier in section 1.1 by differentiating between dynamic, static and temporary static knowledge to be embedded. This was found to be supported well in the board-game format, where static knowledge e.g. the physical laws of technical elements in the energy system was built into the game-rules and more dynamic knowledge, such as regulatory environment was built into the playing cards which can easily be replaced when changes occur. This way, flexibility towards changes in any of the central domains can be maintained.

Table 15 Characteristics of Ensight as a boundary object

Boundary	Characteristics of Ensight
Syntactic (knowledge transfer)	• In the development of Ensight, the syntax of the energy sector was incorporated into everything from scenario cards to game mechanics to allow the players to cross syntactical barriers to other domains in the sector. • The development of common syntax was further supported by extensive use of symbols and deliberate introduction of keywords, together with demonstrations allowing the participants to experience the underlying concepts of words, e.g., by physically building the '*24-hour price cross*' in Lego.
Semantic (knowledge translation)	• Through playing out scenarios together, people from different domains became aware of what 'the others' meant by specific keywords by seeing them act upon their sentences immediately. In addition, this interaction led to an understanding of how, for example, the phrase 'we need a new innovation strategy' was perceived across different levels. • On participant explained this particularly well in the following sentence: 'The most annoying thing about Ensight is that in 1½ hours, it allows the whole team to understand what it took me 15 years to learn'.
Pragmatic (knowledge transformation)	• The core of the game is built around simulating the electricity spot-market to provide a safe environment to try out new things through trial and error. Many experiments were conducted by the players, leading to a transformation of their personal knowledge. For example, one player experimented with a solution for energy storage that proved to work only if everyone acted completely rationally in the market. • Three types of knowledge stability were built into the game, through three types of knowledge repositories: (1) the rules of the game, which govern the game mechanics, represent static knowledge, e.g., the physical infrastructure; (2) the game cards represent temporary static knowledge and can be transformed when new situations arose, e.g., new legislation and technologies; and (3) dynamic knowledge was captured in the way scenarios were planned, which could be changed in minutes, and the sources of this knowledge were most often the players themselves.

According to the classification scheme for boundary objects proposed by (Carlile, 2002; Star, 1989) (presented in Table 2), Ensight would be classified in the *objects, models, and maps* group. However, from our analysis of the functions and structure of Ensight as a boundary object, it became apparent that in addition to addressing the pragmatic boundary of knowledge transformation, Ensight also addresses syntactical barriers by creating a common language of value creation between the domains for knowledge transfer and addresses semantic barriers by allowing the participants to experience the consequences of their interpretations immediately, which supports knowledge translation. Therefore, Ensight should be seen as a small-scale boundary object infrastructure, interacting with other boundary objects, actors and domains within its context. In this way, Ensight fits into iterative as well as linear design process by simultaneously addressing the three types of boundaries, without creating

specific requirements to the process models which are a natural part of the boundary object portfolio.

4 Conclusion

The motivation for this study was to address the lack of concrete support methods for supporting the design of innovations in multidisciplinary teams. With empirical grounding in a larger research study, a serious game was developed as a method to span boundaries between knowledge domains. Structured interviews have been performed with 35 engineering designers from four departments in one company. Controlled experiments with 22 early researchers were conducted. The analysis indicated that the engineering designers reacted positively to the method as an aid for multidisciplinary work, learned key concepts necessary for mutual understanding across domains, were able to change their collaboration behaviour, and produced better results in their multidisciplinary teams than they did without the boundary spanning method. The latter was confirmed across both the interviews and the experiments.

This research has contributed to the development of a boundary spanning method for supporting multidisciplinary teams and is based on empirical research. Three properties have been identified as key to the functional performance of the method, namely, the ability to transfer knowledge by addressing syntactic barriers, the ability to translate knowledge by addressing semantic barriers, and the ability to allow joint transformation of knowledge by addressing the pragmatic barrier. A central property in the structure of the boundary object has been identified in the separation between elements holding static knowledge and between the levels of dynamic knowledge. This property enables an economy of scale in knowledge sharing in combination with flexibility towards changes in dynamic knowledge. High levels of diversity and depth in knowledge are found in literature to increase productivity and innovation height in design teams. The boundary object method developed in this study provides support

for multidisciplinary teams in companies by supporting collaboration in team compositions

with higher levels of diversity and depths of knowledge than without the method.

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8 Appendix

Appendix 1: Ensight

Please visit www.ensightweb.dk for an interactive introduction to Ensight
Choose between making a personal profile on Ensightweb, or using this shortcut:

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Username: Ole - Thesis

Password: ensight
```

ENSIGHT

Determine Rainfall

Determine Demand

Close Supply Bids

Determine Wind

Calculate Price Cross

Trade

Update Balance

Flip and Bid on Cards

Research and Development

Regulatory Frames

Construction

Operation
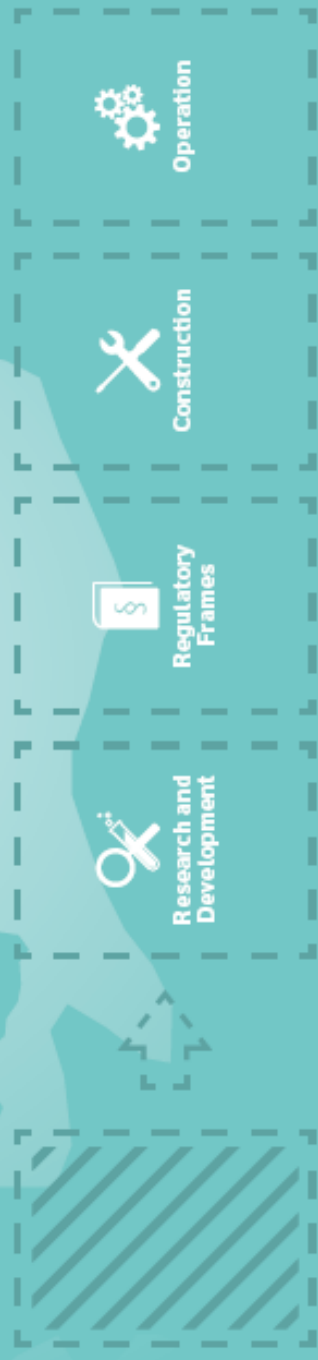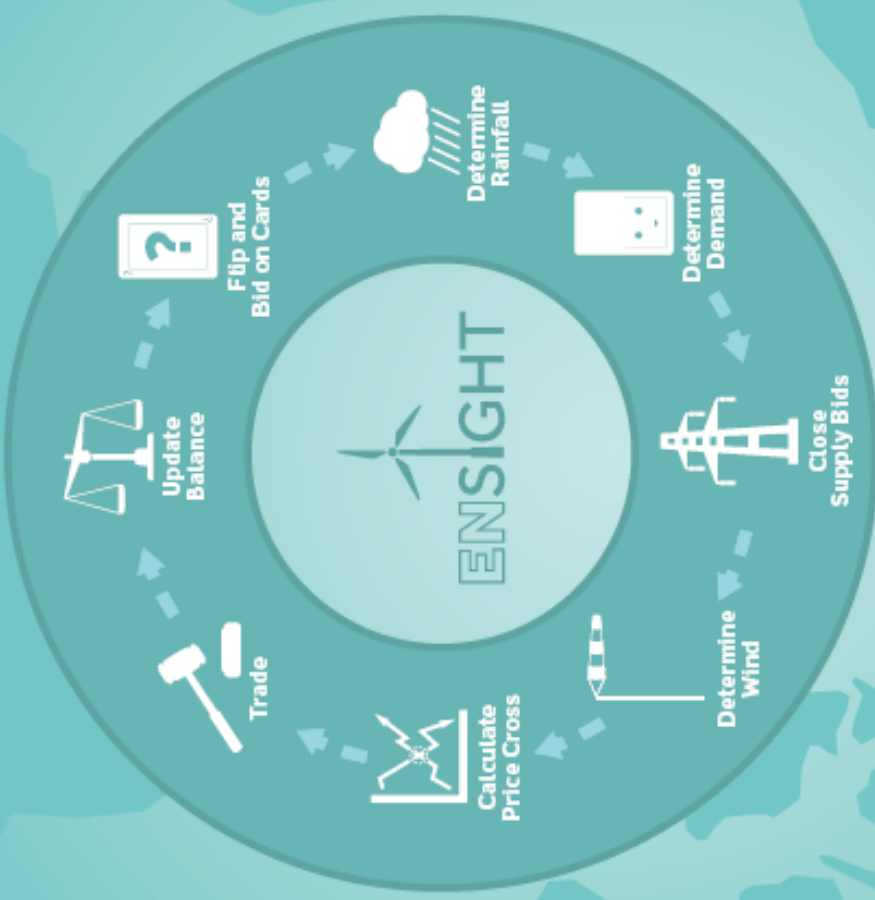
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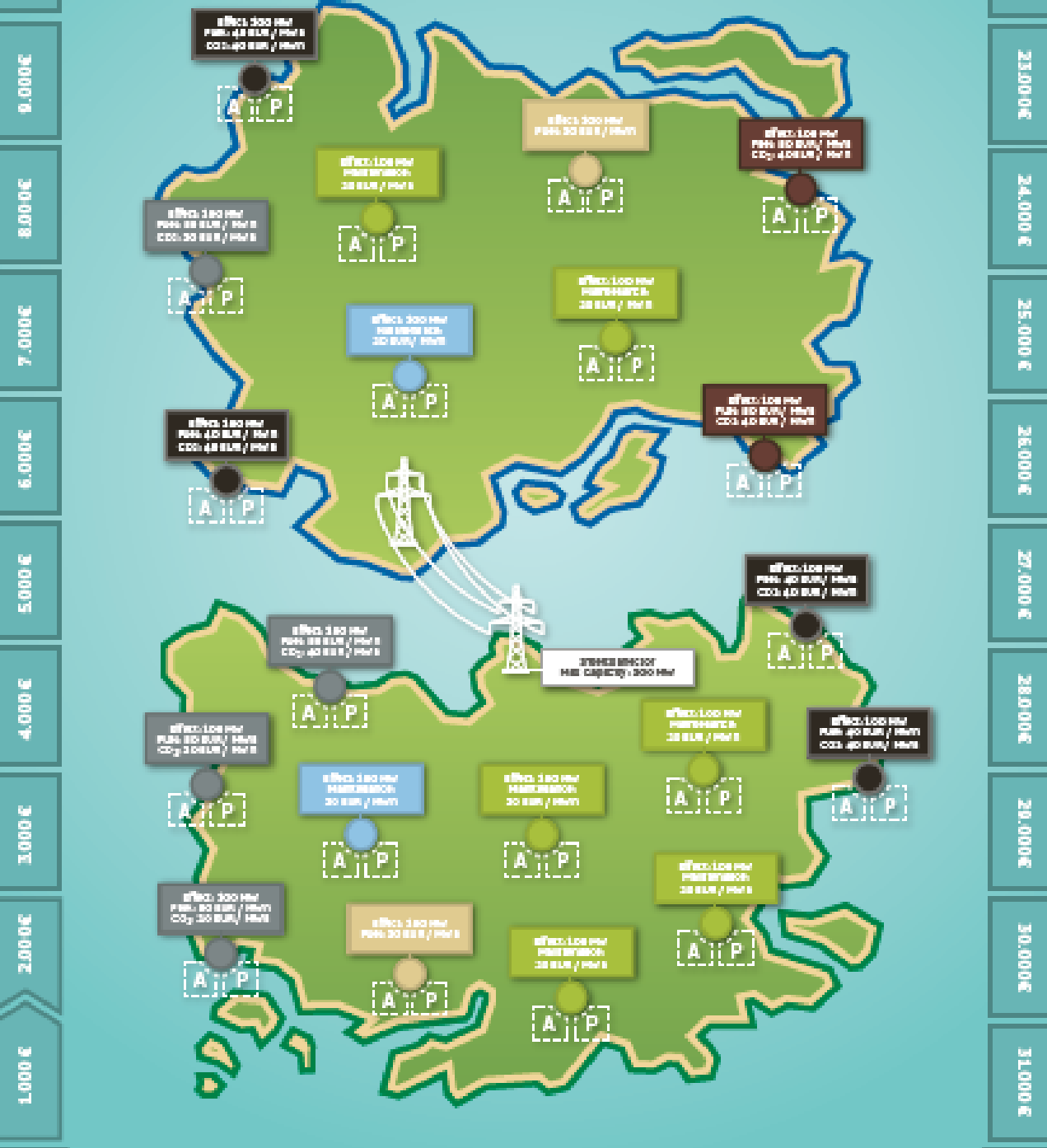
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COAL POWER · OIL POWER · GAS POWER · NUCLEAR POWER · HYDRO POWER · WIND POWER

ENSIGHT
MANUAL

Innovation Centre
Group R&D

DONG
energy

1 Preface

ENSIGHT is, in essence, a captivating method for learning key concepts of the extended energy system by experiencing the effects of regulation, innovation and competition in a simulated game environment.

When developing ENSIGHT, we had three different purposes in mind: 1) Creating a common frame of understanding between business developers from different knowledge domains collaborating on innovation projects 2) Providing technical specialist-staff with a deeper understanding of the value creating market decisions, and 3) Establishing an entertaining platform for educating people with little to no prior knowledge about the energy sector.

To accommodate all three purposes; ENSIGHT turned into a modular game where chaste as well as complex scenarios are played through by the participants, gaining experience about present business challenges and futures yet to come.

The knowledge gained through experiencing future scenarios will strengthen decisions made by participants in the present, when returning to their daily context.

ENSIGHT is developed under the Innovation Centre in DONG Energy and is modelled after the actual Nordic energy spot-market, merging insight from business development projects with results from an industrial PhD project in knowledge management.

On the ENSIGHT-web you find support for professional use of the game in settings such as innovation-project kick-off, strategy deployment and employee development. Furthermore, you will find practical tools including: a development tool for new scenario-decks, a discussion forum and instruction videos for participants and facilitators.

2 Preparation of Ensight

ENSIGHT is designed to be played with one facilitator and from 2 to 10 teams. Each team should consist of 1-4 players; however, the best results are reached with 2 players on each team.

2.1 Game Components

- 1 Facilitator game board
- Scenario game boards
- 200 Action cards grouped in 4 decks
- 6 Screens for secret bidding
- 120 €1000 notes
- 3 Dices (6-sided, 8-sided, 10-sided)
- 1 Booklet with rules
- 1 Bell
- 1 Time-glass

Lego to build the following:
- Spot Market
- 60 power plants
- 200 Team numbers
- 100 Action-card indicators
- 10 Wealth Indicators
- 1Turn Indicator
- Water bricks

2.2 Game board set-up

The facilitator game board controls the progress of the game and is used on all levels of the game. The three scenario game boards represent the three levels of the game:
1 region with up to 10 teams for novice players, 2 regions with up to 6 teams for intermediate players and 3 regions with up to 6 teams for advanced players.
Power plants on scenario game board are distributed either by the facilitator or according to suggestions under "portfolio overview" in the end of this booklet. The ownership of each plant is marked with a LEGO team number, both on bidding bar and scenario game board.

Action Cards

After choosing which level to play, the action cards are placed on the marked area on the facilitator game board.
The selection of action cards is done prior to the game by the facilitator. Based on these choices a different game will unfold every time, either with random effects or as a pre-packed scenario, exploring a deliberately chosen course of events.
If playing on level 1, a deck of appropriate cards are chosen by the facilitator and placed in one pile on the marked field on the board.
If playing on level 2 or 3, a deck of appropriate cards are chosen by the facilitator and placed either in one mixed pile on the marked field, or separated into the four card categories: Research & Development, Regulatory Frames, Construction and Operation.

Screens

If playing on level 1, no screens are used. Instead, all teams leave the table to discuss their strategy and only returns to the table to place their bids.
On level 2 and 3, each team receives a screen, behind which they are to place their bids in secrecy. The screen also provides valuable information for the players during the game on how to bid and calculate prices.

Money

Euro notes are only used on level 2 and 3. These are not distributed from the start, but granted from the facilitator according to credit value of the team shown on the status indicator, with a maximum of 20.000€ / team. The money is used to bid on action-cards and for inter-team trading.
Dices, booklet with rules, bell and time-glass are all kept by the facilitator.

2.3 LEGO constructions

LEGO constructions play a very central part in ENSIGHT: They comprise all indicators on the boards, the spot-market is build from LEGO and so is each power plant bidding-bar.

Price-cross coordinate systems

You need to build as many coordinate systems as there are regions on the game scenario board. (1, 2 or 3)
The basic layout is shown in the Fig. 1; however you can always extend it with more blocks in each direction (price and demand) if desired.
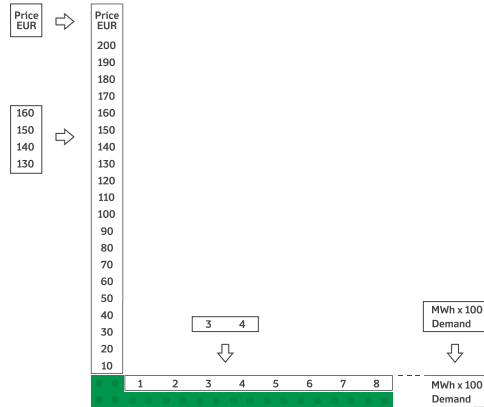
Fig. 1

See description of how the price-cross is used under the turn description.

Power plant bidding-bars

The bidding-bars for each plant are to be build according to the expenses for fuel and CO_2 or maintenance, as shown on the scenario game board. Examples of the constructions are shown in the figures. Oil, Coal, Gas and Nuclear plants are all build as shown in Fig. 2, Wind as Fig. 3 and Hydro as Fig. 4. The two blue bricks on top of the Hydro-plant represent each 50MW of water reservoir and is earned during the game.
Afterwards, the bars are distributed to the teams. On level 1, each team gets the same 6 plants. On level 2 and 3, the facilitator plans how the plants are distributed, however some balanced suggestions are shown in the end of this booklet.

(Wind Power)

Fig. 3

(Gas Power)

Fuel cost CO_2 cost

(Hydropower)

Company in Green Region

Fig. 2
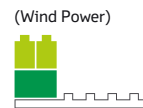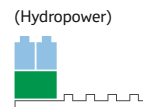
Fig. 4

See description of how the bidding-bars are used under the turn description.

Plant-ownership indicators

On the sheet of stickers, you find the numbers from 1 to 10. These are attached to the thin white 2x2 LEGO plates. Each team marks his power plants on the bidding bars as well as on the scenario game-board. While playing level 1, the plants are only marked on the bidding bars.

Fig. 5

Effect: **100** MW
Fuel: **80** EUR / MWh
CO_2: **20** EUR / MWh

Action-card indicators

The black thin 2x2 LEGO plates are used as they are to signify that an action card is active on one of the power plants.

Fig. 6

Effect: **100** MW
Fuel: **80** EUR / MWh
CO_2: **20** EUR / MWh

Status Indicators

These constructions are small stairs, indicating who is leading the game, by the LEGO man climbing them. Each team receives 1 wealth indicator constructed according to the figure.
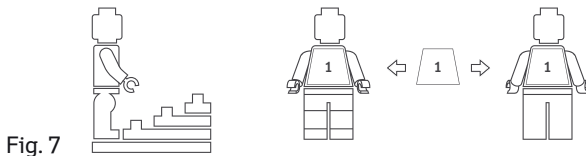
Fig. 7

See description of how the wealth indicator is used under the turn description.

Turn Indicator

This construction is used to keep track of the progress in the game. 1 construction is build according to Fig. 8, and placed in the turn manager on the facilitator game board.

Fig. 8

3 Game Rules

This part contains everything you need to know, in order to get started with the game. As facilitator or advanced user of the game, you can find more inspiration, alternative rules and an online development tool for new scenario-decks on the ENSIGHT web.

ENSIGHT is designed to be played with a facilitator and from 2 teams and up. Each team should consist of 1-4 players; however, the best team dynamics and learning is reached with 2 players on each team.
The object of the game is to go 5 rounds on the Status indicator, or alternatively, to be the highest ranked player on the status indicator after a fixed amount of time e.g. 2 hours.

3.1 Turn overview

ENSIGHT is played according to the turn manager on the facilitator game board, shown in Fig. 9. Therefore, all teams are always actively involved and no waiting for turn is needed.
Please refer to the Box. 1 for dice-rolls descriptions.

1. Each turn starts with every team updating their balance by moving their status indicator on the status bar according to recent trades. Ownership of power plants is updated on bid bars and on the scenario game board.

2. Cards are turned by the facilitator. If playing on level 1, one card is turned affecting everyone. If playing on level 2 or 3, the teams bid on being the first to choose a card.

3. Rainfall is determined by rolling a 6 sided dice. Water-bricks are distributed to each player according to ownership and roll.

4. Power-demand is determined by rolling a 6 sided dice for each region in the game. It alternates between peak and off-peak hours: uneven rounds (1, 3 etc.) are peak hours with high demand. Even rounds (2, 4 etc.) are off-peak hours where the demand is low.

5. Supply bidding is done by deciding which power plants you want to run with in the current round, and place the bid on the bid-bar for each plant according to your desired price. Wind-turbines and hydro plants cannot be used to press up prices. Hydro plants can only produce if you have a full water reserve. The market closes after two time glasses has passed and the facilitator rings the bell.

6. Wind-production on the turbines submitted to the market is determined by rolling a 6 sided dice, always rounding up to the nearest 100MW.

7. Price-cross is calculated by arranging all bidding-bars, with the cheapest first, on the LEGO coordinate system. The plant with the highest price needed to fulfil the demand sets the price for all plants in production. Earnings equal price minus total

costs and the status indicator for each team is moved according to acquired earnings.

8. Trading is where the teams can trade between each other. Everything is possible from trading complete plants to starting an auction on your capacity between the other players. Use your creativity and make someone an offer.

Box. 1   Fig. 9

Rainfall: 1D6
1-2 = 0MW, 2-3 = 50MW, 4-6 = 150MW

Demand (peak / off-peak): 1D6+N*400 / 1D6+N*200
1 = -300, 2 = -200, 3 = -100, 4 = 100, 5 = 200, 6 = 300

Wind Production: 1D6
1-2 = 0 % wind, 2-3 = 50% wind, 4-6 = 100% wind

N= Number of teams; 1D6 = Roll a 6-sided dice
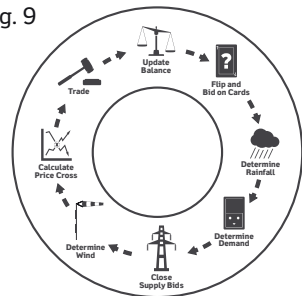
3.2 The game play in detail

Level

Start by selecting appropriate level for the participants. For novice players, it is strongly encouraged to start on level 1, but more advanced players will most likely prefer to start on level 2 or 3. If you are playing with a mixed group, also start with level 1, but make sure that the experienced players are distributed evenly between all teams.

Setting up

Set up the game-board as described in the beginning of this booklet. Now you are ready to distribute plants to the players. For level 1, all teams get 6 plants, corresponding to the 6 fields on the scenario game board. For level 2 and 3, this can be done in several ways:

- Use one of the predefined set-ups described in the end of this booklet under "plant portfolio" – There is one suggested set-up for each level.
- Take turns picking out your plants - It is suggested that each team starts with 6 plants: The team on the left hand of the facilitator starts by picking 3 plants on the map and place their teams number on the field marked "P". Hereafter, the turn to pick 3 plants progresses clockwise until all teams has three plants. The team picking last, then picks 3 more plants, and the turn to pick progresses counter-clockwise until all teams has 6 plants in their possession.
- Distribute an amount of money to each team e.g. 20.000 and select 6 plants pr. participating team. Auction off all the plants to the teams.

Spot-Market

If playing on level 1, the spot-market is placed on the scenario game-board when all plants have been distributed to the players. This way, all teams can gather around the making of the price-cross in every turn.
If playing on level 2 or 3, the role as market-operator takes turns. It starts with the team on the left hand side of the facilitator and moves clockwise around the table. If any decisions need to be made, e.g. choosing between two equally priced power plants, the market operator makes this decision.
It is the responsibility of the market-operator to receive all plants, order them in the price-cross, and tell everyone their earnings, thus, how many fields to move forward.
(1 field= 1000 € = 1 dot on the bidding bar)

Now, the object of the game is to make as high a profit as possible from your portfolio of power plants, round by round as described in the following paragraph.

3.3 The turn in detail

The following paragraph describes a full turn in detail – if any disputes over the rules occur during the game, the team currently having the role as market operator determine what happens, under "fair-play" supervision by the facilitator.

Update Balance

Each turn starts with every team updating their balance by moving their status indicator on the status bar according to recent trades. Also, ownership of power plants is updated on bid bars and on the scenario game board if needed.
If playing on level 2 or 3, the role as market operator is switched to the next team, in a clockwise direction.

Flip and bid on Cards

All cards, at all levels, are turned by the facilitator and read out loud.
If playing on level 1, one card is turned each round, affecting everyone in the game. Therefore, the card deck used needs to be chosen to make sense while applied to everyone at once. It is the responsibility of the facilitator to ensure this by selection.

On level 2 or 3, one card more than the number of teams is flipped each round i.e. if 3 teams are playing, 4 cards are flipped.
In round 1, the cards are flipped and read out loud, but none of them are used yet. All teams can think about the implications of the cards during the round. When second round starts and the "Flip and Bid on Cards" field is reached again, the flipped cards are distributed to the players and then a new set of cards are flipped and ready.
Cards are distributed according to a secret bedding round, using the € - notes, where the winner gets first choice on the cards, no. 2 gets 2nd choice etc. Everything the teams bid is lost afterwards and the teams move back on the status bar accordingly.

In the event of a tie, players go into a 2nd bidding round, with a minimum bed of 5000 €.
It is possible to bid more than your company is worth, by moving backwards on the status line, but never more than 1 full round, corresponding to 40.000 €.
For a discussion of the categories of cards and how they apply to each level, see Action Cards in the Preparations chapter.

Determine Rainfall

Rainfall is determined by rolling a 6 sided dice: 1-2 = 0MW, 2-3 = 50MW, 4-6 = 150MW. The water is distributed to the teams in 50MW water bricks. Water is storable and may be used whenever the team finds it beneficial to produce. Each run of one hydro plant consumes 100MW of water (2 water bricks).
If more than one hydro plant is owned, water is accumulated by each of them i.e. if two plants are owned by a team and the dice roll turns out 50 MW of water, the teams receives 2 times 50 MW = 100 MW of water and is free to save up or use the 100MW immediately on one plant.
The received water is placed on top of the plant, and when full (2 water-bricks placed) the hydroplant is ready for production whenever the player submit it to the spot-market.

Determine Demand

Demand alternates between peak and off-peak hours, which is equivalent to the difference between dinner-time (peak) and midnight (off-peak).
Peak hours (i.e. hours with high demand) are played in uneven rounds (1, 3 etc.).
Off-peak hours (I.e. hours with low demand) are played in even rounds (2, 4 etc.)
Demand is determined by multiplying the number of teams with 200MW for off-peak and 400MW for peak hours and then adding / subtracting 100 to 300 MW by rolling a 6 sided dice: 1 = -300, 2 = -200, 3 = -100, 4 = 100, 5 = 200, 6 = 300. The demand brick is moved on the spot-market according to the outcome of the demand calculation.

Close Supply Bids

Supply bidding is done secretly from competing teams.
Bidding is done by moving the bid-brick as shown on Fig. 10. Hydro plants and wind-turbines cannot be used to set prices, and are always bid-in to cost-price of 20€.
If playing level 1, each team walk away from the game-board and discuss what plants to use, and where to place the price. When the spot-market closes, only the plants that the team wants to produce from can be brought back to the game-board.
If playing on level 2 and 3, the teams make the same choice (which plants to use and to which price) behind their screen. When the market closes, the screen is lifted immediately, and all plants showing are submitted to the market at the given price.
Spot-market is closed when the facilitator sounds the bell, which will happen after 1 or 2 time glasses, according to the preference of the facilitator.
Most often, the passing of 2 time-glasses provide a beneficial market window, in the beginning of the game; whereas 1 passing is sufficient in later rounds.

Fuel cost **CO$_2$ cost**

Company in Green Region

Fig. 10

Determine Wind

Wind-production on the turbines submitted to the market is determined by rolling a 6 sided dice: 1-2 = 0%, 2-3 = 50%, 4-6 = 100%. The percentage is for each player. Thus, if two teams both submitted one turbine for a 50% production, both of them will produce.
Production is always rounded up to the nearest 100MW e.g. If one team submits 1 wind-turbine to the market and the wind-production is 50 %, the wind-turbine will be in production with 100MW.
If a team has 2 turbines submitted for production, in 2 different regions and the production turns out to be 50%, the market operator (the team sitting with the spot-market) decides which one of the two turbines will produce in the current round.

Calculate Price Cross

Calculating price-cross is the responsibility of the team currently being market operator. (The team possessing the LEGO coordinate system).
The price-cross is calculated by arranging all bidding-bars, with the cheapest first (closest to the price-axis), on the LEGO coordinate system. The price for all plants in production is set by the last (and, most expensive) plant needed to fulfil the demand, marked with the brick on the demand axis.
If playing level 1 you now have the price for all teams calculated and can go to *earnings.*
If playing level 2 or 3, excess production from each region is transferred via the interconnectors and competes on neighbouring markets. However, note that each interconnector has a maximum capacity which can never be exceeded.
When using the interconnectors, plants are always moved to where they yield the highest earnings. If two or more plants are equal in price, the market operators decide which plants to move where, always observing that domestic production has priority over production from other regions.
Earnings on each plant equal price minus total production costs
The status indicator for each team is moved according to acquired earnings.

Trade

Trading is where the teams can trade between each other. Everything is possible from trading complete plants to starting an auction on your capacity between the other players.
If playing on level 2 or 3, this fields is also where the "out to tender " cards come into play – If anyone has one of these cards, they have the option of starting an auction on one optional plant not currently owned by anyone. The card-holder selects the plant and comes with the first bid, which can be anything between 0 and their value on the status bar. A company can place themselves in a maximum debt of 40.000€ (on round on the status bar)
So, use your creativity and make someone an offer – this is where you can turn the whole game upside-down!

4 Power Plant Portfolios

4.1 Level 1 – One Price Region

Each team will receive one of each plant from the start. This way the game starts out balanced and all teams can trade on equal terms.
Water reservoirs are full from the start (100 MW)

Plant Overview

Type	Fuel Cost	CO_2 Cost	Total Cost
Wind	0 €/MWh	0 €/MWh	20 €/MWh
Hydro	0 €/MWh	0 €/MWh	20 €/MWh
Nuclear	30 €/MWh	0 €/MWh	30 €/MWh
Gas	80 €/MWh	20 €/MWh	100 €/MWh
Oil	80 €/MWh	40 €/MWh	120 €/MWh
Coal	40 €/MWh	40 €/MWh	80 €/MWh

4.2 Level 2 – Two Price Regions

At level 2, the following distribution of plants provides and interesting and well-balanced game where each of the three teams have different strategic opportunities from the outset.
Water reservoirs are full from the start (100 MW)

Plant Overview

Region	Type	Fuel Cost	CO_2 Cost	Total Cost
Team 1				
Green	Wind	0 €/MWh	0 €/MWh	20 €/MWh
Green	Wind	0 €/MWh	0 €/MWh	20 €/MWh
Green	Wind	0 €/MWh	0 €/MWh	20 €/MWh
Green	Coal	40 €/MWh	40 €/MWh	80 €/MWh
Green	Gas	80 €/MWh	20 €/MWh	100 €/MWh
Blue	Oil	80 €/MWh	40 €/MWh	120 €/MWh
Team 2				
Green	Wind	0 €/MWh	0 €/MWh	20 €/MWh
Green	Coal	40 €/MWh	40 €/MWh	80 €/MWh

Region	Type	Fuel Cost	CO₂ Cost	Total Cost
Green	Gas	80 €/MWh	20 €/MWh	100 €/MWh
Blue	Wind	0 €/MWh	0 €/MWh	20 €/MWh
Blue	Coal	40 €/MWh	40 €/MWh	80 €/MWh
Team 3				
Green	Gas	80 €/MWh	20 €/MWh	100 €/MWh
Blue	Wind	0 €/MWh	0 €/MWh	20 €/MWh
Blue	Coal	40 €/MWh	40 €/MWh	80 €/MWh
Blue	Gas	80 €/MWh	20 €/MWh	100 €/MWh
Blue	Oil	80 €/MWh	40 €/MWh	120 €/MWh
Tender				
Green	Hydro	0 €/MWh	0 €/MWh	20 €/MWh
Green	Nuclear	30 €/MWh	0 €/MWh	30 €/MWh
Blue	Hydro	0 €/MWh	0 €/MWh	20 €/MWh
Blue	Nuclear	30 €/MWh	0 €/MWh	30 €/MWh
Interconnectors				
Connecting: Blue & Green region	Maximum Capacity 300 MW			

4.3 Level 3 – 3 Price Regions

While playing at level 3, the following suggested distribution gives the opportunity to start out with absolute dominance in each region, each with primary focus on one technology.
From this outset, many interesting liberalisation strategies can be explored.
Water reservoirs are full from the start (100 MW)

Plant Overview

Region	Type	Fuel Cost	CO₂ Cost	Total Cost
Team 1				
Blue	Oil	80 €/MWh	40 €/MWh	120 €/MWh
Blue	Gas	80 €/MWh	20 €/MWh	100 €/MWh
Blue	Nuclear	30 €/MWh	0 €/MWh	30 €/MWh
Blue	Hydro	0 €/MWh	0 €/MWh	20 €/MWh
Blue	Hydro	0 €/MWh	0 €/MWh	20 €/MWh
Blue	Hydro	0 €/MWh	0 €/MWh	20 €/MWh

Team 2				
Green	Coal	40 €/MWh	40 €/MWh	80 €/MWh
Green	Coal	40 €/MWh	40 €/MWh	80 €/MWh
Green	Coal	40 €/MWh	40 €/MWh	80 €/MWh
Green	Gas	80 €/MWh	20 €/MWh	100 €/MWh
Green	Wind	0 €/MWh	0 €/MWh	20 €/MWh
Green	Wind	0 €/MWh	0 €/MWh	20 €/MWh
Team 2				
Red	Coal	40 €/MWh	40 €/MWh	80 €/MWh
Red	Coal	40 €/MWh	40 €/MWh	80 €/MWh
Red	Coal	40 €/MWh	40 €/MWh	80 €/MWh
Red	Gas	80 €/MWh	20 €/MWh	100 €/MWh
Red	Nuclear	30 €/MWh	0 €/MWh	30 €/MWh
Red	Nuclear	30 €/MWh	0 €/MWh	30 €/MWh
Tender				
Blue	Gas	80 €/MWh	20 €/MWh	100 €/MWh
Blue	Nuclear	30 €/MWh	0 €/MWh	30 €/MWh
Blue	Hydro	0 €/MWh	0 €/MWh	20 €/MWh
Blue	Hydro	0 €/MWh	0 €/MWh	20 €/MWh
Blue	Wind	0 €/MWh	0 €/MWh	20 €/MWh
Green	Coal	40 €/MWh	40 €/MWh	80 €/MWh
Green	Gas	80 €/MWh	20 €/MWh	100 €/MWh
Green	Wind	0 €/MWh	0 €/MWh	20 €/MWh
Red	Coal	40 €/MWh	40 €/MWh	80 €/MWh
Red	Coal	40 €/MWh	40 €/MWh	80 €/MWh
Red	Oil	80 €/MWh	40 €/MWh	120 €/MWh
Red	Gas	80 €/MWh	20 €/MWh	100 €/MWh
Red	Nuclear	30 €/MWh	0 €/MWh	30 €/MWh
Red	Hydro	0 €/MWh	0 €/MWh	20 €/MWh
Red	Wind	0 €/MWh	0 €/MWh	20 €/MWh
Interconnectors				
Connecting: Blue & Green region	Maximum Capacity 500 MW			
Connecting: Red & Green region	Maximum Capacity 800 MW			

Appendix 2: ICED 11 Paper

KNOWLEDGE MANAGEMENT CHALLENGES IN NEW BUSINESS DEVELOPMENT - TRANSITION OF THE ENERGY SYSTEM

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ABSTRACT

The empirical study, this paper is based upon, aimed to identify and describe knowledge management challenges, throughout the new business development process. This paper reports findings from the study, as well as the framework used for analysing the knowledge management challenges, which can be applied to other case studies for comparison. Six interviews and 2 full-day workshops, gathering the perspectives of 76 people from an energy-utilities company forms the empirical background of the study. Six categories of knowledge management challenges were identified and, within each, central issues were extracted and changes throughout the new business development process investigated. Significant differences from the early to the late stages of this process were identified, including; shift from personal to codified knowledge transfer and need for supporting integration of knowledge from diverse domains better in the early phases. Furthermore, two new roles of the early phase, besides instigating projects, were found. This study contributes to the development of support tools for knowledge management in industry and to research with a deeper understanding of the new business development process.

Keywords: Knowledge Management, New Business Development, Innovation, Empirical Study

1 INTRODUCTION

Knowledge, especially about new technologies and markets, plays a very significant role in the design of the future energy systems and universities; technological research institutes; governments and companies are all engaging in development of technologies, products and services for this future system. Thus, the management of new knowledge from these and other sources; is a key concern. Through describing the specific *knowledge management* (KM) challenges faced during *new business development* (NBD), the aims for developing supporting tools to support the transformation of the energy system can be further clarified and the new business development process itself be further understood.

The approach of this paper is to describe the KM challenges faced in practice by NBD professionals in industry. An empirical study of the product and service design process was set up with an energy utilities company, and the outcome is discussed in this paper.

In the following two sections; new business development processes and knowledge management is discussed, with the aim of providing a frame for answering the research question:

How do the KM challenges change throughout the NBD process, in the context of designing products and services for the future energy system?

1.1 New business development processes

New business development (NBD) processes are concerned with growing the company, through recognising and utilising opportunities arising in the environment of the company. In this way, there are great overlaps between *corporate innovation processes* and *new business development processes*.[1]The term NBD processes will be used throughout this paper, however theories formally assigned to both areas will be drawn upon.
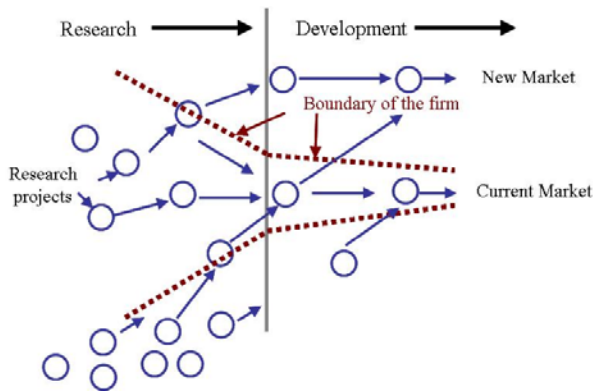
Figure 1: The open innovation funnel [2]
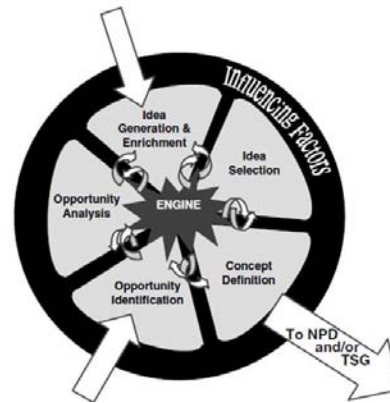
Figure 2: The fuzzy front end of innovation [3]

Chesbrough [2] has developed a model of the innovation funnel, which is shown in Figure 2. This model is made to emphasise the permeable boundary of the NBD process, where knowledge to an increasingly larger extent can pass freely in and out of companies, denoted *open innovation*. However, as Chesbrough's model starts with the existence of research projects, a model for where these projects come from is needed. Koens's [3] model of *the fuzzy front end* describes this very clearly, as an interaction between identifying opportunities, analysing and selecting between alternatives as seen in Figure 1. However, for the purpose of this paper, the two models have been integrated am simplified into the three phases seen in Figure 3: *Preject*, which are all activities going on before an actual project has been initiated, *Transition*, which describes the hand-over from preject to project, and where commitment to the project is established and finally; the *Project phase*, where the NBD project is executed.
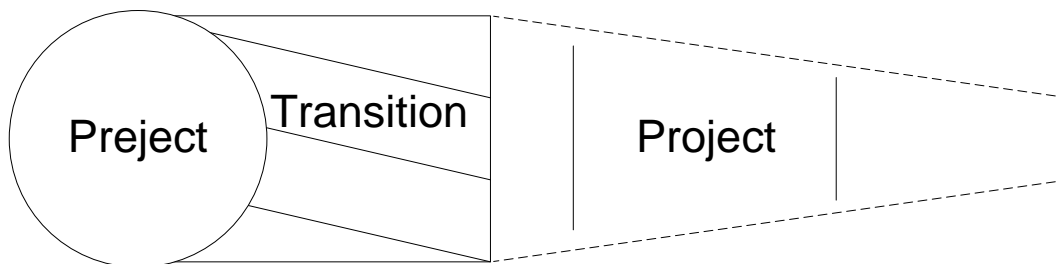
Figure 3: Reference model for the NBD process, adapted from Chesbrough and Koen

Tidd & Bessant [1] argues that knowledge plays a central part in the innovation funnel, as it converts uncertainty to risk, in the sense that the more we know about a given phenomenon, the more we can take a calculated decision about whether or not to proceed, thereby justifying a closer look at KM.

1.2 Knowledge management

The emphasis on KM within the NBD process aligns with current research on *innovation process definition* especially from the field of organisational behaviour [4-6] that recognise the central role of KM in innovation processes. Blackler [7] and Hansen [8] argues further, that KM in practice is closely related to the context in which it plays out, hence, it is expected that the KM challenges will differ from phase to phase and furthermore, this analysis can only be expected to be valid within a similar industrial context. Furthermore, the KM literature was use to construct the coding scheme presented later in Table 2.

2 RESEARCH METHODOLOGY

The aim of this study is to explore the KM challenges throughout a NBD process, including the early project phase, which is seen to be only covered sparsely in current innovation literature.

Yin [9] differentiates between three types of empirical studies, being: 1) Exploratory, which covers questions like "what, "who, and where; 2) Descriptive, which covers research questions like "how many" and "how much" and, finally 3) Explanatory, which covers questions like "how" and "why".

The research question of this study is, based on yin's this distinction, clearly an explanatory study; investigating the operational links between the NBD process in practice and KM challenges.

For explanatory studies, Eisenhardt [10] and Blessing & Chakrabarti [11]argues that theory-building research using cases very often gives a particularly good answer to research questions addressing "how and why" in relatively unexplored areas. Therefore, this study has been designed as such.

2.1 Data Description

The study is based on data gathered through interviews and workshops with business developers in a large Danish energy-utilities company. What makes this company particularly interesting as case study is the fact that they are trying to radically transform the energy system; from 15% sustainable energy to 85% sustainable energy. This transformation introduces extra stress on the NBD personnel in the company, as they are forced to handle new types of knowledge, especially within the non-technical domains, which is both, new to the company, and so far, the behaviour of large socio-technical systems like this is very hard to make a reliable simulation of. Therefore, KM challenges are expected to be more apparent than during *business as usual*.

The company is structured as a concern, where 4 business units handles diverse technical areas such as: exploration and production of oil, production of electricity, sales and distribution of electricity to private and wholesale markets, and, finally, trade with oil, gas, coal and electricity on Nordic and European markets. Data for this study has been collected at the *group R&D* level, which is a part of the executive support group, reaching across all 4 business units. The participants in the study are all employees specifically dedicated to fostering the corporate innovation, and, thereby, the transition of the energy system. 6 interviews, between 1 and 1½ hour duration, were situated and carried out in the company. *All Interviews* were undertaken in a semi-structured manner, with questions in the following categories: 1) Personal Networks and their function 2) The interviewees understanding of innovation, knowledge and decision making (DM) 3) Personal narratives on knowledge flow and DM 4) Experience with Methods & Tools for DM and KM. In addition to interviews, 2 workshops were carried out. First one had 20 participants and lasted 7 hours. The second workshop had 50 participants and lasted 6 hours. *The first workshop* treated 3 topics: 1) Structure and accessibility of knowledge from different domains 2) identification and activation of sources of knowledge and 3) Requirements for selecting the better KM methods. *The second workshop* treated one topic: Ideas for enhancing innovation, stimulated by a presentation of innovation theories and 2 brainstorm methods. This way, there are three angles on the data: Preject, Project and R&D operations, representing viewpoints of 76 People.

Table 1: Overview of Data Used in the Study
[DG = Distributed Generation]

Data Source	Purpose	Methods Used	Participants
R&D Operations	Gaining insight into current issues with the innovation process, as perceived by the department as a whole. Furthermore, the "operations view" provided insight into department level management of NBD projects and projects	2 Workshops	Top Management Senior Management Business developers Specialists
DG Project DG Project	Understanding the specific KM challenges involved with running projects and preject activities that aims to radically transform the energy system and include knowledge from multiple domains	6 Interviews	6 Different Business Developers, involved in both Preject and Project, within DG.

2.2 Coding scheme

Data from the interviews was transcribed and separated into speech bursts, before it was coded according to the coding scheme presented in Table 2. From the workshops, the material produced during the workshops was collected, transcribed and coded according to the same coding scheme.

Development of the coding scheme in Table 2 was driven by the data, but infused with knowledge from literature whenever a new topic emerged. This was seen a more expedient approach than the completely data driven coding used in grounded theory [12] as literature is very rich on explanations of local phenomena, but as no literature so far has described the full picture, the predefined coding schemes common in e.g. psychology [13], didn't exist. The coding scheme is constructed as a syntactical morphology, meaning that by picking one code from each category, it is possible to construct a meaningful sentence, postulating something about the data set.

Table 2: The Coding Scheme for Knowledge Management Challenges in New Business Development

Category	Definition	Codes		References
NBD Phase [Noun]	Reference-category, describing which phase in the NBD process data relates to. See *Introduction* for more details on this particular division of the NBD Process	• Preject • Transition	• Project	[3] [2] [1]
Exploitation of Knowledge [Verb]	A group of activities concerned mainly with transferring existing knowledge, through teaching, mixing teams, capturing information in databases etc. This is the main concern in the majority of KM literature [14]	• Concentration • Dissemination • Externalising	• Collecting • Codified Dissemination • Personal Dissemination	[15] [5] [16]
Exploration of Knowledge [Verb]	A group of activities aimed directly at managing *new* knowledge: how to create it, how to identify it, and how to integrate different knowledge from different domains in order to put it to use.	• Reflection • Monitoring	• Experimenting • Integrating	[15] [17] [3]
Barriers for Knowledge Transfer [Noun]	Identified types of issues with transferring knowledge, both encompassing situations where the transfer is directly from person to person, but also where knowledge is explicated into reports, guidelines, databases, emails etc. as part of the transfer. Transfer of tacit, implicit and explicit knowledge-types all appear within this category.	• Pre-conception of knowledge quality • Ease of Access • Deliberate restricted access • Mediation • Cause for interaction	• Common frame of understanding • Accessibility of source • Knowledge Level Distance • Interpretation difference	[5] [18] [4]
Novelty of Knowledge [Adverb]	Novelty level of the particular knowledge that is handled by the business developers. The scale ranges from knowledge completely new to the world, down to common knowledge that is reused in a different context.	• New to World • New to Firm • New to Org. Unit	• Partly Known / Adapted • Existing	[1] [19]
Knowledge Domain [Noun]	This category defines the object of the above knowledge management activities, being a classification of managed knowledge, based on what the knowledge is *about*. The classification is an extension to distinguishing between market and technology, which is quite frequently used in management literature	• Business model and processes • Development funding • Internal alliance creation • External alliance creation • Regulatory environment	• Insights into user's world • Dynamics of the market • Technical characteristics • Synergies with energy system • Energy resource reliance • All Domains	[20] [14] [17]
Knowledge Retainment Strategy [Verb]	Describes the strategy followed in order to purposefully keep or discard the knowledge in use. The categorisation ranges from consulting external sources and not deliberately trying to retain any knowledge, to the internal creation of knowledge in the company, where all knowledge is possible to retain within the company.	• Spread and Keep • Create internally, keep	• Get externally, keep • Consult external source	[21] [14] [18] [5]

Table 3: Findings from the analysis aggregated in overview form.
Numbers next to codes are given in *percentage of total cross-tabulation (e.g. Project + Exploitation of knowledge)*

Categories	Project	%	Transition	%	Project	%
Exploitation of Knowledge	Dissemination	21,3	Dissemination	49,9	Dissemination	30,3
	Collecting	27,6	Collecting	12,7	Externalising	48,5
	Personal Dissemination	24,5	Externalising	13,1		
	Concentration	13,5	Concentration	11,2		
	Total (explanatory power)	86,9	Total (explanatory power)	86,9	Total (explanatory power)	78,8
Exploration of Knowledge	Integrating	37,7	Integrating	60,5	Monitoring	48,7
	Experimenting	18,7	Reflection	22,7	Reflection	29,2
	Monitoring	30,8				
	Total (explanatory power)	87,2	Total (explanatory power)	83,2	Total (explanatory power)	77,9
Barrier for Knowledge Transfer	Common Frame of Understanding	19,3	Common Frame of Understanding	47,8	Common Frame of Understanding	50,6
	Accessibility of Source	14,5	Accessibility of Source	7,7	Accessibility of Source	13,7
	Cause for Interaction	20,3	Cause for Interaction	18,3	Deliberate Restricted Access	13,7
	Mediation	25,1	Mediation	8,2		
	Pre-conception of knowledge quality	7,8				
	Total (explanatory power):	87,0	Total (explanatory power)	82,0	Total (explanatory power)	78,0
Novelty of Knowledge	New to World	25,7	Existing	16,4	Existing	42,6
	New to Firm	27,0	Partly Known / Adapted	28,6	Partly Known / Adapted	37,5
	New to Org. Unit	31,0	New to Org. Unit	42,9		
	Total (explanatory power)	83,7	Total (explanatory power)	87,9	Total (explanatory power)	80,1
Knowledge Domain	All Domains	41,7	All Domains	24,0	All Domains	22,8
	Business Model and Processes	32,6	Business Model and Processes	32,0	Business Model and Processes	67,8
	Internal Alliance Creation	8,9	Internal Alliance Creation	20,6		
	Total (explanatory power)	83,2	Total (explanatory power)	76,6	Total (explanatory power)	90,6
Knowledge Retainment Strategy	Create internally	50,2	Create internally	46,4	Create internally	32,2
	Spread and keep	21,7	Spread and keep	53,5	Spread and keep	57,8
	Consult external	13,5				
	Total (explanatory power)	85,4	Total (explanatory power)	99,9	Total (explanatory power)	90,0
	Total Project [%]	**75,50**	**Total Transition [%]**	**15,68**	**Total Project [%]**	**8,82**

3   FINDINGS

In this section, the identified KM challenges are presented, as well as an adaptation of the New Business Development model that better fits the findings from this study.

Interviews and the two different workshops were analysed separately, in three different analyses, using the same coding scheme. Table 3 shows the cross-tabulated and aggregated results, in matrix form, with numbers next to codes being calculated *as percentage of category total* i.e. In the top left corner, the code *integration* accounts for 37,7% of the total hits in both *Exploration* and *Preject*. Inside each of the 18 squares, the most significant codes are displayed. Each field has an explanatory power of at least 75% i.e. it explains at least 75% of the total dataset with the displayed codes. In cases where more codes are close to having the same value, all of them are included. In total, there is a little more than 1400 coded elements (workshop suggestions and speech-bursts from interviews) behind the numbers.

3.1   Exploitation of Knowledge

Efficient exploitation of knowledge is one of the cornerstones in KM theory. [14] The analysed case is no exception; however, there is clearly a much more diverse focus on different exploitation activities in the preject and transition phase, than in the project phase. From the explanations in the interviews, it was found that the exploitation activities are high on the agenda in the company, as they see KM as almost similar to knowledge sharing. Knowing that they have challenges with handling new knowledge, they try to solve it though an exploitation approach, which, so far has turned out rather efficient in the project phase, but very inefficient in the preject phase. This finding is very consistent with [15] whom suggests that focus on exploitation activities in radical new innovation, especially where new ideas are conceived, is often overemphasised, whereas focus on strengthening the exploration activities should be emphasised to a higher extend.

Another indication of the different needs in preject compared to project, is the strong focus on *codified* knowledge sharing [8] in the project phase and the just as strong focus on *personal* knowledge sharing [8] in the preject phase. It appears to be quite important in the preject phase, that the knowledge sharing they *do* have is made face to face, avoiding reports, databases etc. thus maintaining the ability to quickly adapt to new situations and fast changing political agendas.

3.2   Exploration of Knowledge

As mentioned above, this category is shown by [15] to be central in especially the early phases of innovative work. However, in this case there was very low explicit focus on explorative activities; they were driven by reactions to problems more than deliberate proactive exploration. Again in this category, clear changes throughout the NBD process are seen, where the knowledge-creating activity *experimenting* only is seen in the preject phase. Specifically, the challenge is to experiment with large socio-technical networks, which are very hard to simulate and very hard to create demonstrations of, as they are often intangible. The importance of experimenting is stressed by the interviewees, as the only way to truly generate new knowledge and insight into technologies as well as market.

Later on, in the project phase; it appears more central to follow what others are doing through *monitoring*, which is further supported by frequent statements from the interviews, where the participants describes the project execution as "putting your nose in the track and running" – It is interesting to compare this to the concept of path dependency [22], which is most frequently applied to a whole organisation, but the above numbers indicate that the preject work seeks to break paths and find new business directions, whereas the project work is deliberately path dependant: They run in the direction they are started in, though they emphasise that they *should* be monitoring what others are doing. Exactly who these *others* are will be touched upon in the end of this section - *across NBD Phases*.

The code *integrating* is a whole different issue – It appears only in preject and transition and seems to be comparably more important in transition. However, it is actually two different challenges that hide behind the numbers: In the preject phase, the integration challenge relates to integrating knowledge from several different, often new, domains of knowledge. In the transition phase, the integration challenge is distinctively between the truth of the company and the new truth that comes with a radically new project idea.

3.3 Barrier for Knowledge Transfer

A surprising finding in this category, is that *common frame of understanding* goes across all categories, but, even though integration between knowledge domains was seen to be a challenge in preject phase, the focus on common frame of understanding is weighed much lower here, than in the subsequent phases. The explanation for this, rather odd, phenomena lies in the *mediation* which scores very high in the same preject phase, compared to other next phases. The preject work is, by nature, very multidisciplinary and the involved actors are aware of this. Therefore, though they would wish for a *common frame of understanding,* they know that it is very unlikely to happen, and instead focuses on the more action oriented "mediation"- In the absence of the common frame, a good translation is the next best thing. However, for the transition and the project phases, the strongest focus is on the frame itself, as they perceive it as possible to generate, through continuous organisational learning.

Cause for interaction starts relatively high, and then wears off throughout the phases. This challenge is related to the exploratory role of the preject activities, as the people monitor the world around the company closely, mainly directed by "cause of the interaction", being ideas for discussion, conferences within their respective field etc.

3.4 Novelty of Knowledge

This category looks very much as one would expect from a traditional closed innovation model [1]: High focus on radically new types of knowledge in the preject phase, with new to world, new to firm and new to organisational unit making up 84 % of the KM challenge-focus. From transition and into the project, there is no longer focus on new types of knowledge, but to work with existing and partly known knowledge, mainly infused in a waterfall manner from the preceding preject phase. However, this picture seems a bit odd, when compared to the fact that the case company are promoting open innovation [23] where focus should be the exact opposite, namely integration of new to the firm knowledge all along the lifespan of projects and close alliances with external partners. The explanation given in the interviews is that the leaders of the innovation department sees open innovation as a viable and unavoidable path for developing the future energy systems, as no one company can change the full system alone, as it covers an immense amount of business areas, where only a few of them are of interest to an energy utilities company. However, there is a great amount of inertia in a company this size and there is very little practically applicable methods at the time for actually *doing* and *managing* open innovation when arriving to the project phase, thus the transition is harder.

In the transition phase, there seems to be a an opening, at least to *new to organisational unit* knowledge, however, behind this number lies the explanation that the knowledge that is new to the unit in fact is the knowledge that comes from the preject phase, and only to a very limited extend, knowledge from the external world

3.5 Knowledge Domain

In the preject phase, there is a strong emphasis on *all domains* which does not mean that all the domains are equally important, but that the interaction *between* the domains is of special importance. This supports very well the discussion above; that the integration mediation and experimenting between knowledge domains are of larger importance than any one of the domains in isolation. However, this picture is disturbed a bit by the *Business model and Processes* domain, which is very central across all phases. This owe to twp primary reasons: firstly, as the company struggles with expedient methods for open innovation in an energy system in transformation, they are very cautious about *how* to develop project ideas. Secondly, as the importance of *internal alliance creation* also suggest, the internal sale of the developed project idea is a central challenge, but requires intimate knowledge about the many *development methods* and *business models* followed by the receiving business units. If a project is based on an unfamiliar development method, or is opposed to the business model of the receiving business unit, it will be very hard for them to engage in the transition and take over the project.

3.6 Knowledge Retainment Strategy

The last category deals with how knowledge is retained within the company, which to some extend relates back to the prior discussion on path dependency. A high level of self-create knowledge and absorption makes the company more path dependant, as the competencies needed to create and absorb complex knowledge are the same competencies that will make the company follow a specific technological path [21] Earlier, it was argued that the there was a high degree of path dependency in the projects, while the preject activities are more able to follow, and even create, new paths.

When looking at the numbers, the *spread and keep* starts at 22 % and rises downstream ending with a little short of 60% in the project phase. At the same time, *create internally* has the opposite curve, moving from 50% in the preject phase, down 32% in the project phase. Together with *consult external* appearing only in the preject, the numbers support the earlier statement about path dependency; however, it doesn't create the impression of a completely agile company, with high degree of internal creation. The main challenge here is a classic one: to balance the company's path dependency, with the agility. However, a third argument arises from the interviews to explain the high degree of internal creation of knowledge in the supposedly agile front end: the front end doesn't just execute a strategy, it is actually active in the creation of the R&D strategies and this way it creates paths that other companies follow. This is an addition to the agility / absorption discussion in the way that a strong normative path can be laid out for others to follow, but this approach of course presupposes a large amount of control over market and technologies within the energy system.

3.7 Across New Business Development Phases

As it was mentioned in both *novelty of knowledge* and *exploration of knowledge* there is evidence in the study, that even though the company aims for open innovation, it can be very hard to actually incorporate it in practice. What is furthermore seen is that the problem of openness seems to increase throughout the process. Returning for a bit to *monitoring* knowledge, from the *exploration* category, the interviewees explain that monitoring in the project phase is very different from monitoring in the preject phase: In the former, the team is looking for solutions to challenges they are facing in the project right now, and in general, they monitor *internally* in the company for these solutions. In the latter, the preject phase, the team is actively looking outside the company's boundaries for inspiration and complementary knowledge that can leverage their own. To improve this situation, more openness is needed in later stages of the project, especially because of the often very long lead-times within this industry, where the world changes a lot from a project is started till it finishes years later. The Challenge is thus to maintain openness, while still working efficiently on the project.

Another finding across the categories, is that, contrary to believe in practice and the majority of literature, the main purpose of the preject is more diverse than being the instigator of new ground-breaking projects. Instigation is an important role, however, it was seen that both a great deal of *new process knowledge* and *new strategic knowledge* is created in the preject activities. There is traditionally not a great deal of focus on these side-effects though they were seen to be quite central to the overall management of the NBD process, and in cases where projects fail, they become the primary positive outcome, constituting organisational learning through revised strategies, tools and general assumptions about markets and technologies.

4 CONCLUSIONS & IMPLICATIONS

This paper has described a case study carried out in the energy utilities sector, and explained KM challenges identified throughout the New Business Development process.

The literature review disclosed a gap regarding KM challenges and how these change throughout the New Business Development Process, which has been addressed in this paper. Furthermore, the data-driven literature review disclosed the 6 categories: Exploitation of knowledge, exploration of knowledge, barrier for knowledge transfer, novelty of knowledge, knowledge domain and, finally, knowledge retainment strategy as the key areas of interest to understand these KM challenges.

6 interviews and 2 workshops were analysed with a coding scheme based on these categories, representing the view of, in total, 76 people involved in business development; either as business developers, technology specialists, project managers or senior managers. As such, results of the study represent the viewpoints of these people, which all belong to the same company, however the viewpoints represent equally three different angles, being preject activities, project activities and R&D operations. Large differences between KM challenges in the three New Business Development phases were identified, indicating that support for KM needs to allow for these differences to persist. Specifically, the differences identified were:

- Emphasis on personalisation as means for knowledge transfer in preject, where codification is more relevant in the project phase.
- Support for exploration in the early phases, especially in relation to integrating knowledge from diverse domains and enabling experiments with non-tangible complex products to create new knowledge for use in projects, R&D Strategies and general knowledge of the company

- Enable the projects to monitor not only internal solutions to current problems, but also scanning outside the company for inspiration and leveraging of open innovation
- A need for establishing a common frame of understanding, or at least, better mediation between team members with different domain-backgrounds is seen to be increasingly important; when dealing with high diversity of knowledge domains in complex systems.

The preject phase was discovered to have at least two more functions, than instigating new projects based on absorption and creation of knowledge, which is the prevalent description in literature, as well as in the currently studied practise. These two functions are: 1) to generate strategic knowledge i.e. R&D Visions and Strategies, based on in depth knowledge about the socio-technical energy system, created through the direct work with developing new products and services for the system. 2) to create a general body of process, product and market knowledge, to make accessible for the running projects. This knowledge was seen to be created through the role as *first mover* in terms of new development methods as well as new markets and new technologies, in the company.

For research, the contribution is to address the gap in literature identified with empirically grounded insights, which in the future are planned to be expanded with more cases studies, as well as more data from this first case study.

For Industry, this study creates the foundation of further development of KM support tools, specifically aimed at supporting each phase in the innovation process in the best possible way.

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Appendix 3: Semi-structured interview guide

Location:		Date:
Start:	End:	Duration:
Structure: interview, semi-structured		
Name:		Age:
Retirement date:		Years at DONG Energy
Previous history : Education:		
Team worked with:		Position in team:
DONG energy history:		
Follow up interview required:		Reason for follow up:
Willing to be contacted for clarification:		Contact address:
Request data prior to publishing:		
Task: Task stage of process:		
Comments:		
Evaluation:		

Normal Introduction

LANGUAGE AND RECORDING OF THE INTERVIEW

The interview will be carried out in English.

If any words that are used throughout the interview should cause any confusion, please don't hesitate to comment on it, as it is very important that we agree on the terms used.

Is it okay with you, that I record the interview?

The recordings will not be distributed to any outsiders as I'm covered by the same confidentiality agreements that you are.

Furthermore, you will be kept anonymous.

PRESENTATION OF THE PROJECT AND THE INTERVIEWER

I'm a part of the Knowledge and Cognition group from DTU in Lyngby which, for the time being is comprised of 3 master students (one working with DONG Energy as well), 4 PhD. Students a research assistant and an associate professor as group leader.

All of us are working with *engineering knowledge management*, which is best described as "knowledge management applied to the field of engineering-design and innovation"

My project aims to understand how to integrate knowledge related to new technologies and how to support decision making when assessing these new technologies

The purpose of this interview is to map how you work with knowledge and information in the early phases of "radical" innovative projects, by discussing concrete projects.

LENGTH OF THE INTERVIEW

App. 1 ½ hour

TOPICS OF THE INTERVIEW

1. Assessment of knowledge (e.g. technology)

2. Methods for accessing and absorbing the knowledge

ANY QUESTIONS?

Do you have any questions before we start the actual interview?

1ST TOPIC – GENERAL INFORMATION ABOUT THE INTERVIEWEE

1. Could you please describe yourself, and your position in the company?
   - Name
   - Age
   - Formal Position and Project Contribution (Decisions and Project-Producing)
   - Company history
   - Education and Competencies

2ND EGOCENTRIC NETWORKS AND THEIR FUNCTIONALITY ("TRIANGULATED")

2. Identify your personal Network
   - Who do communicate with? (E.g. Functions internally and externally)
   - With what purpose (why)?
   - How are you in contact (all the different ways)
   - When are you in contact with these? (related to project phases)
   - Are you contacted by them?
3. Identify important Knowledge
   - Identify different types of knowledge relevant for your contributions to the project
   - Where in the Innovation process is it relevant? (and why)
   - Where do you get it from (if from a person, who?)
4. Decision
   - Which kind of decisions are you involved in? (both on advisory and DM basis)
   - What knowledge do you need to support the decision?
   - Who are you in contact with in relation to the decision (the group)?
   - When is the decision really made (related to the innovation model)
   - What are the main risks related to a decision?

3RD TOPIC – UNDERSTANDING OF INNOVATION, KNOWLEDGE AND DECISION MAKING

5. What defines, in your opinion (and in DONG Energy):
   - Innovation?
   - Knowledge Management, and who is responsible for it (HR, IT, IC others?)
     - In which ways (if any) do you see its importance, and why?
   - Decision-Making, and what DM processes have you been involved in?
6. How does these terms relate to the project(s) you are currently engaged in?
   - Issues? (e.g. related to the Innovation model)
   - Solutions? (e.g. related to the Innovation model)

7. Could you describe the part of Cleantech / LEP project that you have been involved in from the beginning, focusing on:
    o What kinds of knowledge were transferred?
    o From which source (internal and external), to which receiver; and why these?
    o How and when (which stage) was it transferred (focus on transfer situations)
    o With what purpose was it transferred?
8. Why was the project initiated, and how was the "go" decision made?
    o Could you describe the decision process in detail? (e.g. think, see, do)
9. Which kinds of knowledge have informed the decisions that already have been made in the project? (both ad-hoc decisions and formal gate decisions)
10. How was the knowledge represented?

5TH TOPIC – THE EVERYDAY USE OF METHODS AND TOOLS

11. Which are, in your opinion, the most important methods/tools in use related to: (please, discriminate between ad-hoc tools and formal tools and state why they are important)
    o For Decision making?
    o For Knowledge handling?
        ▪ To become aware of new relevant knowledge?
        ▪ To assess and decide on the inclusion of the knowledge?
        ▪ To absorb and integrate the knowledge?
        ▪ To spread knowledge in the organisation?
12. Are there any shortcomings in the applied tools that you feel is critical?
13. Are you using scenarios as a method in your work (In any way, also scenarios made by other)
    o What is the purpose of using scenarios?
    o Which kinds of knowledge do you build the scenario from?
    o Which are the advantages and disadvantages of using scenarios?
    o How was the use of scenarios introduced?
    o Are there formal methodologies for building scenarios within DONG that apply to this kind of project?

Appendix 4: Audit trail for observations

Collection point	Date for collection	Context	Short Description	Method	Duration
	18.11.2008				
1		Innovation Centre	IC meeting	Obs	3,5
	24.11.2008				
2		Innovation Centre	Discussion of Innovation themes in DE	Obs	2,5
	27.11.2008				
3		Innovation Centre	Innovation Strategy Input	Obs	1
4	02.12.2008	Innovation Centre	Summary and presentation of Report on Relation mapping	Obs	2
	03.12.2008				
5		Innovation Centre	Feedback discussion on Relation Map Report	Obs	2
	03.12.2008				
6		Innovation Centre	Feedback discussion on Relation Map Report	Obs	2
7	09.12.2008	Innovation Centre	IC meeting	Obs	3
	07.01.2009				
8		Group R&D (Executive Support)	R&D Network Day in Frederiksdal	Obs	8,5
9	15.01.2009	Innovation Centre	IC meeting	Obs	3
10	02.02.2009	Innovation Centre	IC meeting	Obs	3
11	04.02.2009	Innovation Centre	Feedback on the report and applicability of relation mapping with LINKS	Obs	3
12	25.02.2009	Cleantech / LEP	Discussion of DE's Interest in Local Energy Production	Obs	1
13	25.02.2009	Group R&D (Executive Support)	R&D Department Meeting	Obs	2
14	09.03.2009	Group R&D (Executive Support)	Discussion of roles in supporting Innovation	Obs	2
15	18.03.2009	Innovation Centre	IC meeting - extended for discussion on terminology	Obs	4,75
16	24.03.2009	Group R&D (Executive Support)	Introduction course for new employees	Obs	7
17	02.04.2009	Group R&D (Executive Support)	R&D Department Meeting	Obs	2
18	29.04.2009	Innovation Centre	IC meeting	Obs	3
19	13.05.2010	Cleantech / LEP	LEP/Cleantech Project	Int	1,5
20	18.05.2009	Cleantech / LEP	Boundaries between VPP, Cleantech and etrans	Obs	1
21	19.05.2009	Innovation Centre	IC meeting	Obs	3
22	25.05.2009	Group R&D (Executive Support)	Discussion on the deep (lean) departments view on KM	Obs	1
23	26.05.2009	Cleantech / LEP	LEP/Cleantech Project	Int	1,5
24	26.05.2009	Group R&D (Executive Support)	Discussion of HR's role in KM	Obs	1
25	28.05.2009	Cleantech / LEP	Business case scenario discussion relating to B2B angle on LEP	Obs	2
26	29.05.2009	Cleantech / LEP	First meeting between Cleantech and LEP	Obs	1
27	02.06.2009	E-Trans	3 days workshop at KDS structuring Anthr. Data	Obs	24
28	08.06.2009	Group R&D (Executive Support)	2 days R&D seminar "from Idea to Reality"	Obs	16
29	10.06.2009	E-Trans	Last day in the 6 days etrans workshop	Obs	8
30	15.06.2009	Cleantech / LEP	Discussion on the use of balanced scorecards to measure innovation	Obs	1
31	23.06.2009	Cleantech / LEP	LEP/Cleantech Project	Int	1,5
32	24.06.2009	Cleantech / LEP	LEP/Cleantech Project	Int	1
33	25.06.2009	Innovation Centre	IC meeting incl. External presentation	Obs	3,25
34	29.06.2009	Cleantech / LEP	LEP	Int	1,5
35	02.07.2009	E-Trans	Discussion about etrans project	Obs	1
36	12.08.2009	Group R&D (Executive Support)	Status meeting in the R&D dept.	Obs	1
37	14.08.2009	E-Trans	Kick-off seminar for internal Etrans project	Obs	3,5
38	21.08.2009	E-Trans	Etrans kick-off reflection	Obs	1
39	03.09.2009	Group R&D (Executive Support)	R&D Department Meeting	Obs	2
40	21.09.2009	Innovation Centre	Workshop on Knowledge Management	WS	7
41	29.09.2009	Innovation Centre	IC FCS meeting - Meetings now separated into technologies	Obs	3
42	04.11.2009	E-Trans	2 Days Workshop "knowledge transition from etrans" with Andrew	Obs	16
43	02.12.2009	Innovation Centre	IC - FCS Meeting	Obs	3
44	03.12.2009	Group R&D (Executive Support)	R&D Department Meeting	Obs	1,5
45	08.12.2009	E-Trans	Idea development workshop at nimb	Obs	5,5
46	14.12.2009	Group R&D (Executive Support)	HR - Intranet Strategy workshop "knowledge sharing"	Obs	3
47	13.01.2010	Innovation Centre	IC - FCS Meeting	Obs	3
48	14.01.2010	E-Trans	Etrans Concept evaluation meeting	Obs	5,5
49	21.01.2010	E-Trans	Etrans Feedback from DONG energy meeting	Obs	7
50	29.01.2010	Group R&D (Executive Support)	R&D Department Meeting	Obs	2
51	02.02.2010	Innovation Centre	IC - FCS Meeting	Obs	3
52	04.02.2010	Background	Interview about the innovation in the energy sector	Int	1,5
53	26.02.2010	E-Trans	Workshop with IDEO on starting up eflex on knowledge from etrans	Obs	5,5
54	04.03.2010	Innovation Centre	2 days teambuilding in the Innovation centre - theme: Internationalisation	Obs	16
55	09.03.2010	E-Trans	etrans review meeting	Obs	1
56	12.03.2010	Group R&D (Executive Support)	HR's role in knowledge sharing	Obs	1,5
57	17.03.2010	E-Trans	Technology concerns in etrans Regis	Obs	1,5
58	22.03.2010	Group R&D (Executive Support)	R&D Department Meeting	Obs	2
59	24.03.2010	Innovation Centre	IC - FCS Meeting (theme: internationalisation, presentation by me)	Obs	3
60	30.03.2010	Innovation Centre	Workshop on analysing the innovation network around VPP / FCS	Obs	7
61	08.04.2010	E-Trans	Re-igniting the emobility concept at KDS	Obs	3
62	09.04.2010	Innovation Centre	Status meeting on knowledge management	Int	0,5
63	13.04.2010	Group R&D (Executive Support)	PhD club meeting - communication seminar and cross BU discussions	Obs	8
64	15.04.2010	Group R&D (Executive Support)	Extra ordinary R&D Dept. Meeting: Knud is leaving	Obs	1,5
65	22.04.2010	Group R&D (Executive Support)	Development-function Seminar: Balancing creativity and structure	WS	8

66	26.04.2010 Innovation Centre	Historical evolution of the VPP project	WS	2
67	26.04.2010 Group R&D (Executive Support)	Good-bye reception: Partnership manager let go	Obs	1
68	03.05.2010 Innovation Centre	Status meeting SVITSU PhD project: The need for dynamic modelling	Obs	2
69	11.05.2010 Group R&D (Executive Support)	Workshop on global leadership competencies - DONG Energy view	WS	1,5
70	21.05.2010 Innovation Centre	Information meeting with orientation from CHANI	Obs	0,5
71	31.05.2010 Innovation Centre	IC Meeting - Flexible costumer Solutions	Obs	3
72	05.06.2010 DONG Energy	Family day in Legoland	Obs	6
73	24.06.2010 Innovation Centre	Etrans Exposition in DONG Energy meeting centre	Obs	2
74	25.06.2010 Innovation Centre	IC Meeting - reinventing the innovation centre under Jacob (DM Review)	Obs	3
75	02.07.2010 Group R&D (Executive Support)	Goodbye to the people being transferred to new business in power	Obs	1
76	02.07.2010 Group R&D (Executive Support)	Promotion reception for JABOE becoming VP R&D and C&R	Obs	1
77	12.08.2010 Innovation Centre	IC Meeting	Obs	4,5
78	23.08.2010 Group R&D (Executive Support)	Workshop on global leadership competencies - Collected stakeholders DI	WS	4
79	23.08.2010 Innovation Centre	IC Meeting	Obs	4,5
80	13.09.2010 Innovation Centre	IC Meeting (remote report and update)	Obs	4,5
81	20.09.2010 Innovation Centre	Status on IC Activities with CHANI	Int	1
82	24.09.2010 Innovation Centre	Status on IC with SVITSU	Int	2
83	28.09.2010 Innovation Centre	IC Meeting - whole IC again (remote report and update)	Obs	4,5
84	11.10.2010 Innovation Centre	IC Meeting (remote report and update)	Obs	3,5
85	28.10.2010 Innovation Centre	PhD's in IC Group meeting	Int	2
86	08.11.2010 Innovation Centre	IC Meeting (remote report and update)	Obs	4
87	29.11.2010 Innovation Centre	Status Meeting on IC Activities	Int	1,5
88	01.12.2010 Innovation Centre	IC Meeting (remote report and update)	Obs	4
89	07.12.2010 E-Trans	Status on Etrans activities with KLBAG	Int	2
90	17.12.2010 E-Trans	Status on Etrans activities with KLBAG	Int	2
91	19.01.2011 Innovation Centre	Status on innovation activities with SVITSU	Int	1,5
92	10.03.2011 Innovation Centre	Knowledge Sharing in IC	Int	1
93	10.03.2011 Innovation Centre	SharePoint services for innovation centre	Int	1
94	16.03.2011 Innovation Centre	Discussion of team site for IC on SharePoint for codified knowledge sharing	WS	2
95	22.03.2011 Innovation Centre	Discussion of general issues in IC	Int	1
96	23.03.2011 Innovation Centre	Discussion of regulatory innovation in dynamic markets	Int	1
97	23.03.2011 Group R&D (Executive Support)	Concept for university collaboration with new partnership manager	WS	2
98	29.03.2011 Group R&D (Executive Support)	Meeting-series with the head of technology development on Innovation	Int	2
99	30.03.2011 Innovation Centre	ENSIGHT concept development	WS	3
100	01.04.2011 Innovation Centre	ENSIGHT concept development	WS	1
101	04.04.2011 Innovation Centre	IC meeting	Obs	5,5
102	08.04.2011 Group R&D (Executive Support)	University collaborations and collaborative R&D	Int	2
103	08.04.2011 Innovation Centre	Requirements and needs for a SharePoint system in innovation	WS	5
104	11.04.2011 Group R&D (Executive Support)	Phone-meeting on serious games in HR	Int	1
105	12.04.2011 Innovation Centre	ENSIGHT concept development	WS	4
106	13.04.2011 Innovation Centre	SharePoint services for innovation centre	Int	1
107	15.04.2011 Innovation Centre	ENSIGHT concept development	WS	5
108	15.04.2011 Group R&D (Executive Support)	Brainstorm on connect and innovate - crowd sourcing in DONG Energy	WS	1
109	28.04.2011 Innovation Centre	ENSIGHT concept development	WS	2
110	04.05.2011 Group R&D (Executive Support)	Meeting with IT Uni. On behalf of serious games Pers. Tech. In DONG	WS	2
111	09.05.2011 Group R&D (Executive Support)	Academic central organisation - requirements for knowledge society	WS	2
112	10.05.2011 Innovation Centre	Sparring on ENSIGHT as innovation facilitator	WS	2
113	14.05.2011 DONG Energy	Family day in Legoland with colleagues	Obs	6
114	18.05.2011 Innovation Centre	Status on ENSIGHT	Obs	1
115	19.05.2011 Innovation Centre	Test of ENSIGHT with players from IC	Obs	2,5
116	23.05.2011 Innovation Centre	Response to ENSIGHT	Obs	2
117	30.05.2011 Innovation Centre	Broader test of ENSIGHT	Obs	2
118	31.05.2011 Group R&D (Executive Support)	AC and DONG Energy - how might universities contribute to knowledge econ.	Obs	5
119	06.06.2011 Innovation Centre	IC meeting	Obs	5,5
120	08.06.2011 Group R&D (Executive Support)	ENSIGHT with trainees in DONG Energy	Obs	3
121	09.06.2011 Group R&D (Executive Support)	Discussion of Knowledge sharing and the relation to IPR	Int	2
122	22.06.2011 Innovation Centre	Discussion of Transmedia solutions for knowledge management	WS	2
123	22.06.2011 Group R&D (Executive Support)	Input discussion on crowd sourcing in biomass innovation	Obs	1,5
124	24.06.2011 Group R&D (Executive Support)	Energy together - concept and network	Obs	2
125	30.06.2011 Innovation Centre	ENSIGHT - concept discussion	Int	0,5
126	30.06.2011 Innovation Centre	KM issues and status on KM project	Int	1,5
127	06.07.2011 Group R&D (Executive Support)	Siemens pictures of the future collaboration discussion	Int	1
128	07.07.2011 Group R&D (Executive Support)	Meeting series with the head of technology development on KM in Inno.	Int	2
129	11.07.2011 Innovation Centre	Energy together - concept and network	Obs	2
130	11.08.2011 Innovation Centre	Strategy discussion and the possibility of dissemination through academia	Obs	1,5
131	16.08.2011 Group R&D (Executive Support)	Energy together - concept and network	Obs	3
132	22.08.2011 Group R&D (Executive Support)	Energy together - concept and network	Obs	2
133	24.08.2011 Innovation Centre	ENSIGHT tested and used in external collaboration with DTU	Obs	4
134	25.08.2011 Innovation Centre	Workshop on how to collaborate on research in the future	Obs	8
135	29.08.2011 Innovation Centre	Current issues with knowledge in IC	Int	1,5
136	01.09.2011 Innovation Centre	Follow-up meeting with DTU on partnership within intelligent grids	Obs	1
137	07.09.2011 Innovation Centre	Two-day seminar on strategy for each innovation platform	WS	12
138	09.09.2011 Group R&D (Executive Support)	Workshop on scenarios, transmedia and Siemens collaboration	WS	2
139	06.10.2011 Innovation Centre	IC Meeting	Obs	5,5
140	28.10.2011 Group R&D (Executive Support)	Workshop on innovation strategy with S&D	Obs	2
141	04.11.2011 Group R&D (Executive Support)	Broad demonstration of ENSIGHT	Obs	1,5
142	07.11.2011 Innovation Centre	IC meeting	Obs	5,5
143	12.12.2011 Innovation Centre	IC meeting	Obs	5,5
144	10.01.2012 Group R&D (Executive Support)	ENSIGHT - Train the trainer started	Obs	2
145	16.01.2012 Innovation Centre	ENSIGHT Web -version for dissemination	Obs	1
146	19.01.2012 Innovation Centre	Results from PhD - discussion and validation	Int	1,5
147	23.01.2012 Innovation Centre	ENSIGHT - train the trainer programme	Obs	2
148	13.02.2012 Innovation Centre	Results from PhD II - communication of results	Int	1,5
149	29.03.2012 Innovation Centre	ENSIGHT event with DONG people	Obs	3
150	13.04.2011 Innovation Centre	2 day innovation centre seminar - innovation process management	Obs	8

Appendix 5: Code definitions

Complete coding scheme for the decision category

Categorized Codes	*Definition*
Practices	
External authority	Decision is driven by advice from an external authority such as Gartner or Bain
Persuade network to support	Key stakeholders are mobilized to drive decisions through political processes
Core capability utilization	Decision is based upon the best utilization of the firms core capabilities
Business model Alignment	Alignment with the business model(s) are used decisive factor
Fit requirements	The decision is taken based on fit with a specific set of limiting requirements
Fit foresight	The decision is taken based on fit with one or more future expectations
Best requirements fit	Decision based on which alternative is the best fit to a set of requirements
Best foresight fit	Decision based on which alternative is the best fit with future expectations
Decision-maker behavior	
Explicit Personal	Deliberately taken by an aware individual
Explicit Social	Deliberately taken by an aware group of individuals
Implicit Personal	Taken by a person without him being readily aware of making a decision
Implicit Social	Taken by a group of individuals, without these being readily aware of it
Centralization	
Centralized	Decision making is sought done centrally by e.g. a decision board or the CEO
Intermediate	Decisions are done centrally, but with high direct involvement of the team
De-centralized	Decision making is sought done locally in organizational units by e.g. teams
Object behavior	
Rational	Decision pertaining to a rational defined future e.g. upgrades in the grid
Hybrid	Decisions pertaining to a hybrid between rational and irrational future
Irrational	Decisions Pertaining to an irrationally defined future e.g. user behavior

Complete coding scheme for the knowledge category

Categorized Codes	Definition
Innovation Phase	
Front end	*Covers the early part of the NBD process, in which goals are not yet defined*
Transition	*Transition of results from the front end to product development*
Product development	*Goal-directed phase in which a goal and the means to reach it have been defined*
Exploitation of Knowledge	
Concentration	Activity concentrating knowledge in a super-node, e.g., a domain specialist
Dissemination	Distribute and share knowledge either in codified or personal form
Externalizing	Activity making people's personal knowledge explicit, e.g., writing words down
Collecting	Adding and combining knowledge in, e.g., a database for later retrieval
Codified dissemination	Transfer of explicit knowledge directly, e.g., by writing an article
Personal dissemination	Transfer of knowledge without explicating it first, e.g., through apprenticeship
Exploration of Knowledge	
Reflection	Processing of new knowledge at the individual or social level to create clarification
Monitoring	Surveillance of knowledge fields and new ideas internally and externally
Experimenting	Creation of new knowledge and ideas through experimentation in a wide sense
Integrating	Combining knowledge with the aim of creating new ideas and concepts
Barriers for Knowledge Transfer	
Preconception of knowledge quality	The recipient's perception of the source as an authority within its domain
Ease of access	How easy the process of establishing a link to a source or recipient is
Deliberate restricted access	Barrier created to protect IPR, strategies and other sensitive information
Mediation	Absence of mediating device, e.g., drawings, or a facilitator that conveys knowledge
Cause for interaction	Lack of reason to interact with potentially interesting knowledge sources
Common frame of understanding	Absence of social frames of understanding, e.g., shared business model/vision
Accessibility of source	How able the seeker is to locate and utilize a needed knowledge source
Knowledge level distance	Relative distance in knowledge level between the source and recipient
Interpretation difference	Barrier created by significant differences in cognitive frames of the people interacting
Novelty of Knowledge	
New to world	Knowledge completely new to everyone in the world
New to firm	Knowledge that is completely new to the firm but not necessarily to others
New to organizational unit	Completely new knowledge to, e.g., the team but not necessarily to others
Partly known/adapted	Partly known knowledge but adapted to a new specific context of use
Existing	Knowledge already known widely in the firm, unit and world in general
Knowledge Domain	
Business model and processes	How to develop the idea or technology into an appropriate business concept
Development funding	Knowledge on how to fund a project to develop the ideas or technologies at hand
Internal alliance creation	The political process by which internal support for ideas is generated
External alliance creation	Knowledge about how support, e.g., visions through alliances with universities
Regulatory environment	Process knowledge on how regulatory frame affects ideas/can be affected
Insights into user's world	Knowledge about the behavior of users and the reciprocal effects on innovations
Dynamics of the market	Macro-scale market insights about market forces, entry barriers, and fluidity
Technical characteristics	Micro-level knowledge about the characteristics of the specific technology at hand
Synergies with energy system	Macro-level energy system: Interactions between elements in the power grid
Energy resource reliance	Insights into a strategic energy resource future, e.g., biomass sourcing or wind
All domains	How to develop the idea or technology into an appropriate business concept
Knowledge Retention Strategy	
Spread and keep	Obtain knowledge from internal source, thereby spreading and securing it
Create internally, keep	Create the knowledge internally and evolve competencies at the same time
Obtain externally, keep	Consult external sources but learn and develop new internal competencies
Consult external source	No retention – External sources are used to provide specific answers

Complete coding scheme for the foresight category

Categorized Codes	Definition
Source temporality	
Past experience	Experiential knowledge is sought out e.g. historical data or solutions
Current context	Contextual knowledge is sought out for description of the current world
Future contexts	Knowledge about the future is sought out, describing opportunities, goals etc.
Source type	
Internal political	Source of knowledge inducing expectation is internally political e.g. manager
Internal specialist	Source of knowledge inducing expectation is internally specialist e.g. R&D Pro.
External political	Source of knowledge inducing expectation is externally political e.g. politician
External specialist	Source of knowledge inducing expectation is externally specialist e.g. consultant
Model paradigm	
Determinist	Principal actor's view is that there is one definable future
Constructivist	Principal actor's view is that there are multiple equally plausible futures
Future temporality	
Near future	The expectation tries to assess the near future (Tactic)
Mid future	The expectation tries to assess the medium term future (Strategic)
Far future	The expectation tries to assess the far future (Visionary)
Formal acceptance	
Personal	Expectation is held as a personal belief, shared by no or few others
Social	Expectation is socially negotiated and commonly accepted in the team
Codified	Expectation is written down and represents the company's official expectation
Relationship	
Normative	Desired future that actors or groups will actively work towards realizing
Desired	A future that is desired by the actors or groups but not actively pursued
Indifferent	Expected evolution of the future, however no actors are emotionally attached
Feared	An expected future that the principal actor fears, but doesn't act to avoid
Threatened	The principal actor considers future threatening and actively counteracts it
Methodology	
Method	Expectation created through use of a formal method e.g. scenario or roadmap
No Method	Expectation created with no use of formal methods – e.g. personal beliefs
Role	
Strategist	Used for exploring new business fields, generate visions and gain consensus
Initiator	Works as an initiator of projects and activities e.g. by identifying needs & techs
Opponent	Expectation is used to perform "sanity checks" of concepts to increase quality